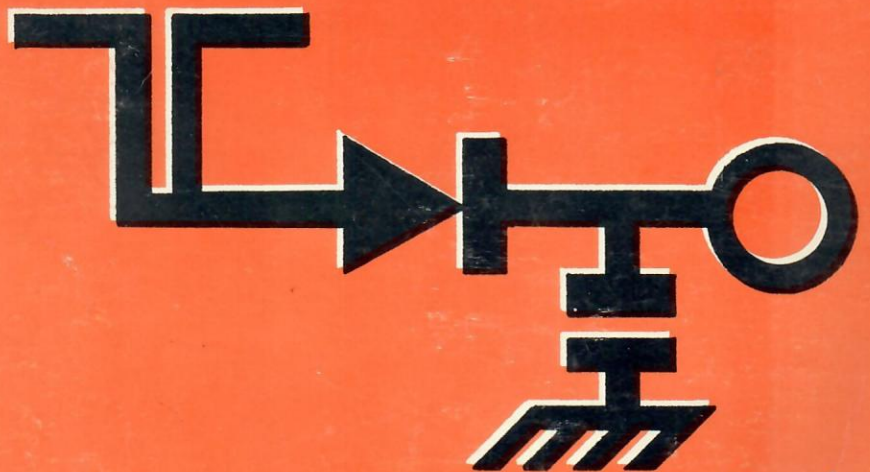




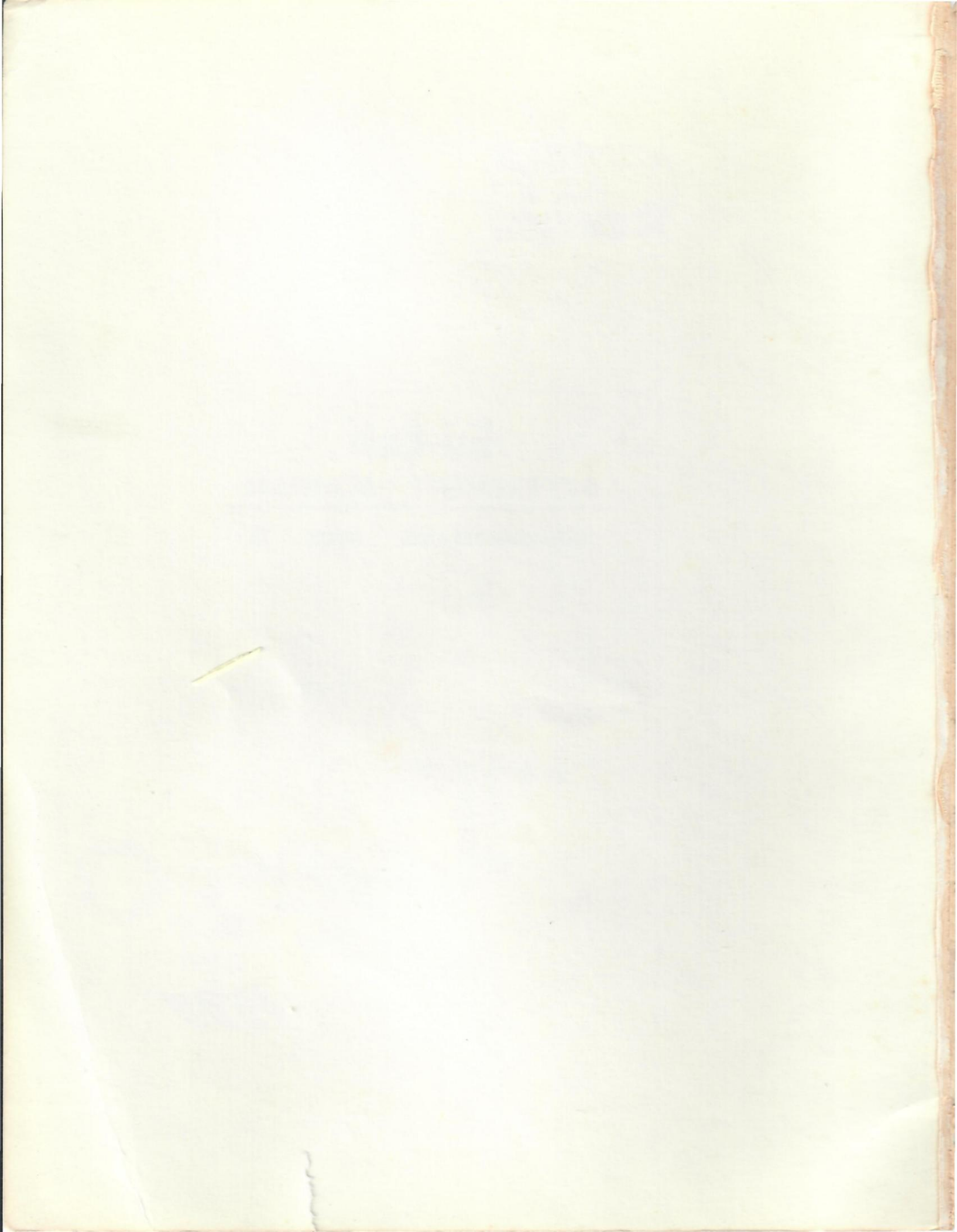
Ed-Lab

EXPERIMENT MANUAL

COMMUNICATIONS BOOK III



CES INDUSTRIES, INC.

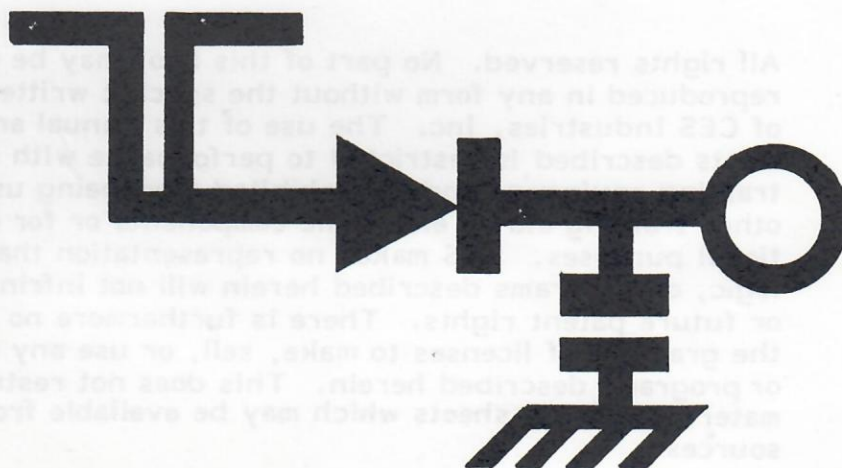




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School _____

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EXPERIMENT MANUAL

COMMUNICATIONS

UNIT NO. 8

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ISBN 0-86711-026-0
Printed in United States of America

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Farmingdale, New York 11735
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Safety is good common sense. The Ed-Lab equipment is designed with all current limited and voltage limited Power Supplies so that there is no danger to the student when touching any wires and no danger of burning-out any of the electronic components.

DO NOT USE AN EXTERNAL POWER SUPPLY WITH THE ED-LAB.

While working in the laboratory, the student is exposed to many different types of equipment, power tools, soldering irons, test equipment, drills, rotating machinery, and so on. The 120 volt power socket can cause a shock, and the shock can result in your jumping or falling. Care should be exercised while working on any equipment including automobiles, television sets, carpentry tools, as well as electricity and electronics.

Do not get involved in any "horsing-around" or in practical jokes. Don't throw anything in the lab. Don't drop the equipment off the bench or on your foot. Don't burn the line cord with a soldering iron. If you remove the Ed-Lab front panel, don't touch the 120 volt line-cord connections in the rear while the plug is still connected to the socket.

If an accident occurs, notify your instructor, shut off all power, and administer first aid as necessary. Your instructor should review with you the safety requirements in your laboratory.

If you observe an accident involving electrical shock,
DON'T JUST STAND THERE - DO SOMETHING!

RESCUE OF SHOCK VICTIM

The victim of electrical shock is dependent upon you to give him prompt first aid. Observe these precautions:

1. Shut off the high voltage.
2. If the high voltage cannot be turned off without delay, free the victim from the live conductor. **REMEMBER:**
 - a. Protect yourself with dry insulating material.
 - b. Use a dry board, your belt, dry clothing, or other non-conducting material to free the victim. When possible **PUSH - DO NOT PULL** the victim free of the high voltage source.
 - c. **DO NOT** touch the victim with your bare hands until the high voltage circuit is broken.

FIRST AID

The two most likely results of electrical shock are: bodily injury from falling, and cessation of breathing. While doctors and pulmotors are being sent for, **DO THESE THINGS:**

1. Control bleeding by use of pressure or a tourniquet.
2. Begin **IMMEDIATELY** to use artificial respiration if the victim is not breathing or is breathing poorly:
 - a. Turn the victim on his back.
 - b. Clean the mouth, nose, and throat. (If they appear clean, start artificial respiration immediately. If foreign matter is present, wipe it away quickly with a cloth or your fingers).
 - c. Place the victim's head in the "sword-swallowing" position. (Place the head as far back as possible so that the front of the neck is stretched).
 - d. Hold the lower jaw up. (Insert your thumb between the victim's teeth at the midline - pull the lower jaw forcefully outward so that the lower teeth are further forward than the upper teeth. Hold the jaw in this position as long as the victim is unconscious).
 - e. Close the victim's nose. (Compress the nose between your thumb and forefinger).
 - f. Blow air into the victim's lungs. (Take a deep breath and cover the victim's open mouth with your open mouth, making the contact air-tight. Blow until the chest rises. If the chest does not rise when you blow, improve the position of the victim's air passageway, and blow more forcefully. Blow forcefully into adults, and gently into children.



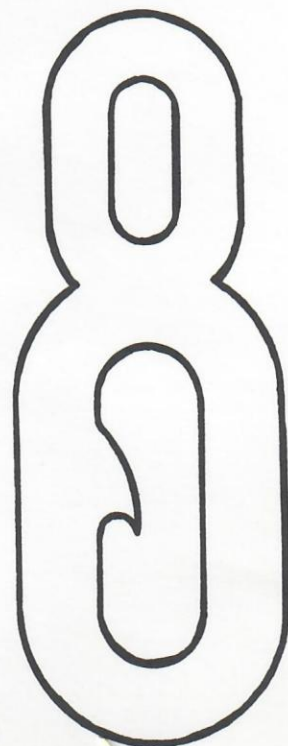
- g. Let air out of the victim's lungs. (After the chest rises, quickly separate lip contact with the victim allowing him to exhale).
- h. Repeat steps f. and g. at the rate of 12 to 20 times per minute. Continue rhythmically without interruption until the victim starts breathing or is pronounced dead. (A smooth rhythm is desirable, but split-second timing is not essential).

DON'T JUST STAND THERE - DO SOMETHING!



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16. Linear Frequency Control
17. Instrumentation Laboratory System
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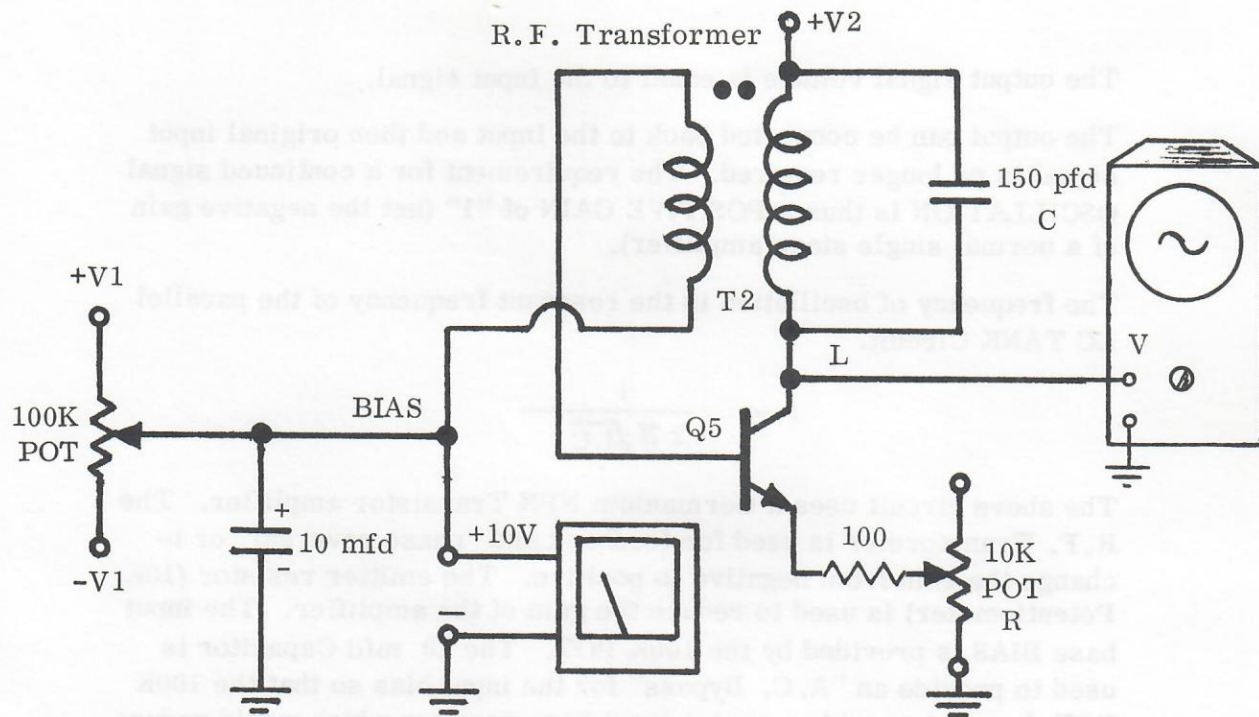


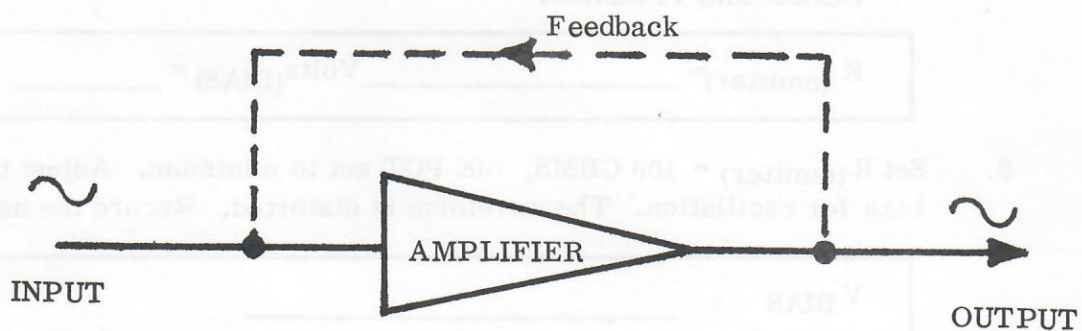
Figure 1-1 Feedback Oscillator

Objective:

You will connect an amplifier output back to the input with "POSITIVE FEEDBACK" to result in a Sinewave Oscillator.

Description:

Consider an amplifier with an input signal and a positive gain of "1".



The output signal voltage is equal to the input signal.

The output can be connected back to the input and then original input signal is no longer required. The requirement for a continued signal OSCILLATION is thus a POSITIVE GAIN of "1" (not the negative gain of a normal single stage amplifier).

The frequency of oscillation is the resonant frequency of the parallel LC TANK Circuit.

$$f = \frac{1}{2\pi\sqrt{LC}}$$

The above circuit uses a Germanium NPN Transistor amplifier. The R. F. Transformer is used for feedback and "phase reversal" or to change the gain from negative to positive. The emitter resistor (10K Potentiometer) is used to reduce the gain of the amplifier. The input base BIAS is provided by the 100K POT. The 10 mfd Capacitor is used to provide an "A. C. Bypass" for the input bias so that the 100K POT does not provide a series input base resistor which would reduce the gain. The meter measures the Bias Voltage.

Procedure:

1. Wire the circuit. Be sure to set the voltages (+V1 and -V1) at the maximum (clockwise). Be sure that the transformer polarities are properly connected.
2. Observe the Oscillator Output on the Oscilloscope. Adjust the Bias (100K POT) and the gain (10K POT) for an "undistorted" output. Record the bias voltage and approximate emitter resistance (10K POT) setting.

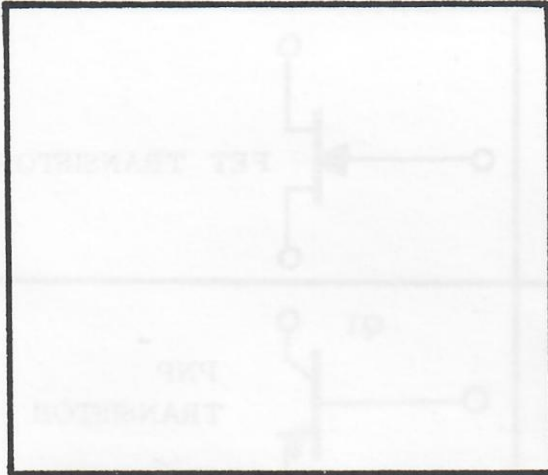
Germanium Transistor

R (emitter) = _____ Volts (BIAS) = _____

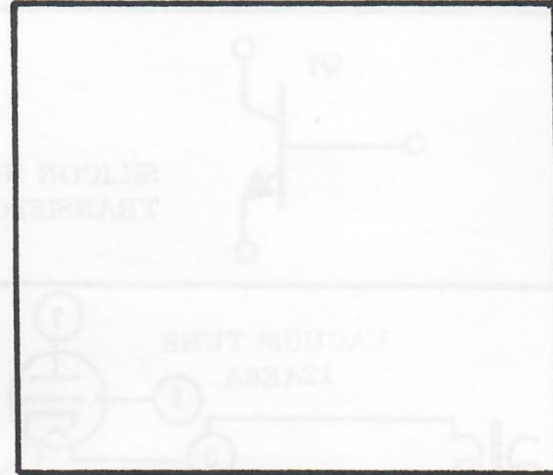
3. Set R (emitter) = 100 CHMS, 10K POT set to minimum. Adjust the bias for oscillation. The waveform is distorted. Record the new bias:

V_{BIAS} = _____

4. Sketch both the sinewave and the distorted sinewave outputs.



SINEWAVE OUTPUT

 $R_{\text{emitter}} =$


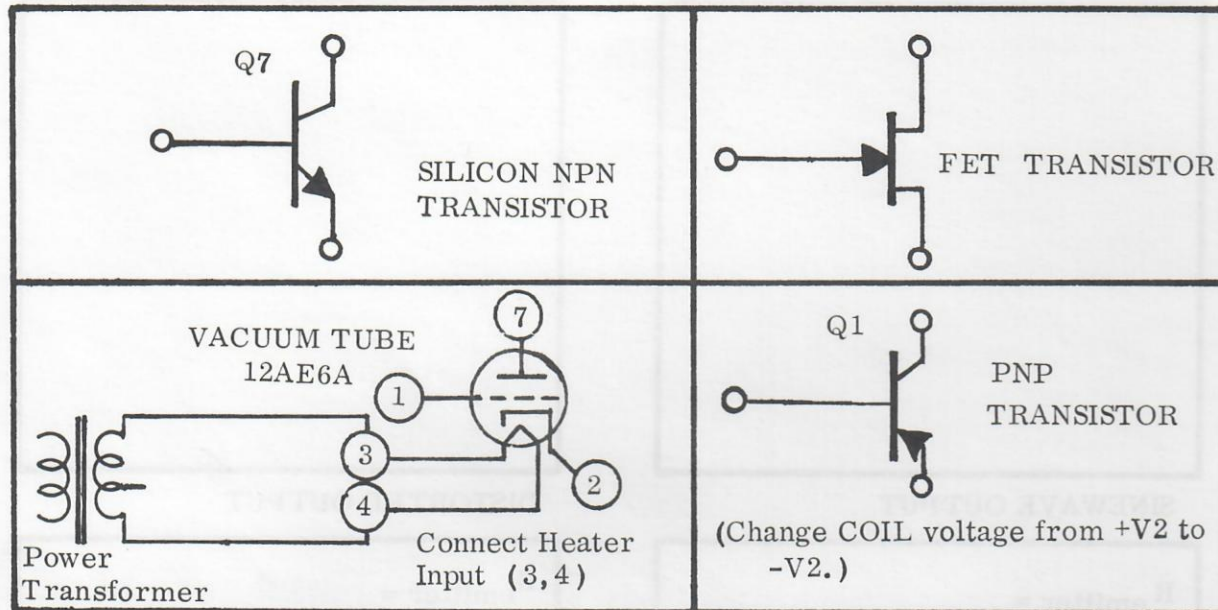
DISTORTED OUTPUT

 $R_{\text{emitter}} =$

5. Measure the frequency of operation using a TIME BASE on the oscilloscope or using the Oscilloscope and a Signal Generator with a LISSAJOUS PATTERN. Frequency = _____
6. Active elements include Transistors, (Bipolar NPN and PNP - Silicon and Germanium), FETs(Field Effect Transistors), and Vacuum Tubes. Circuits using different elements generally require different designs and different values of resistance for gain and bias. However, in the basic oscillator circuit above, all of the other active circuit elements will function.

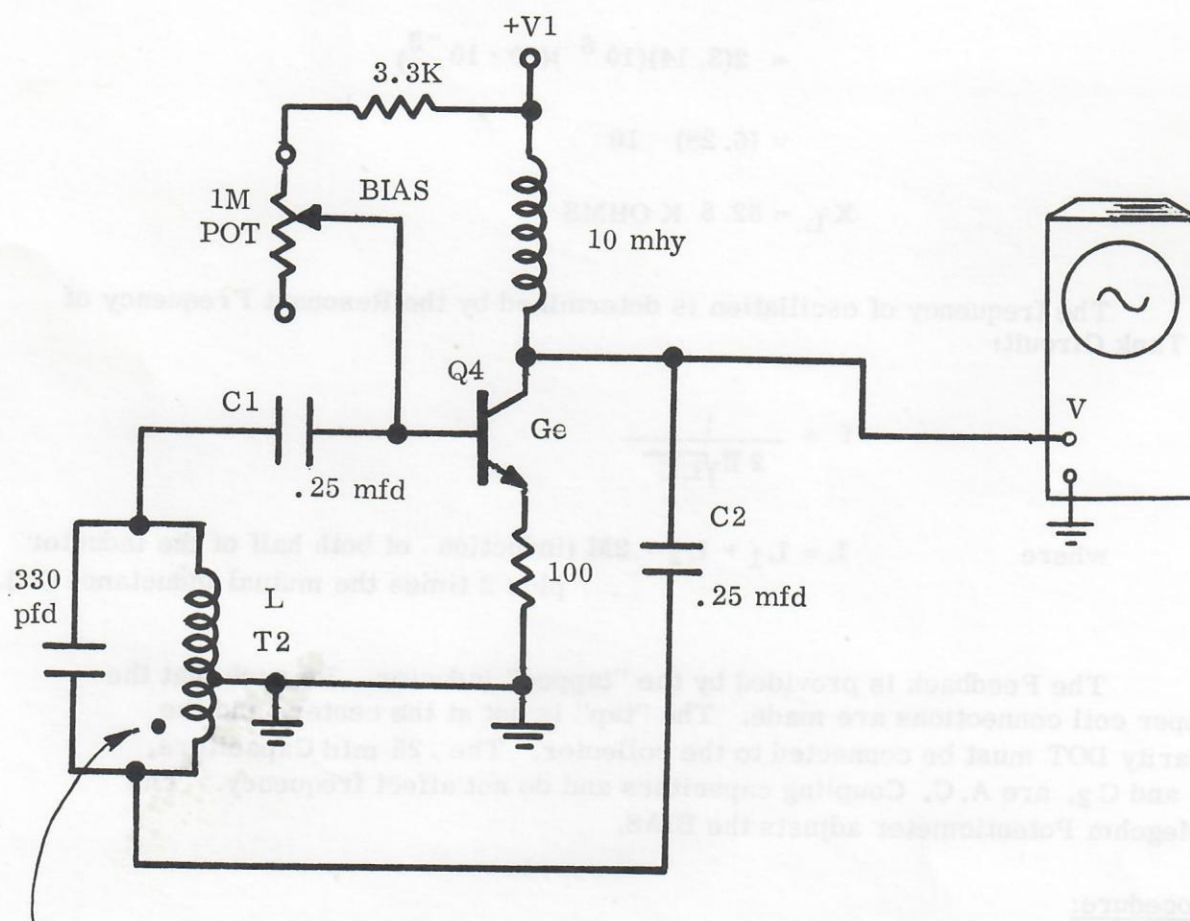
Replace the Germanium NPN Transistor in this circuit with the following elements. Set the Emitter Resistor to "0" and adjust the Bias for the "best" signal. Then adjust both the Bias and Emitter Resistors for a sinewave oscillator output.

Substitute the components shown below and enter the data in the tables below:



(After Adjustment)

	R _{emitter} = 0	ADJUST		SINEWAVE (Yes or No)
		R _e =	BIAS =	
Germanium Transistor Q5				
Silicon Transistor Q7				
FET Transistor				
Vacuum Tube 12AE6A				
PNP Transistor Q1				



Note: Position of Polarity DOT (upside down from panel orientation)

Figure 2-1 Hartley Oscillator

Objective:

You will construct a HARTLEY Oscillator where a single "tapped" inductor is used to provide positive feedback from the collector output to the base input.

Description:

The above circuit uses an inductor (10 mhy coil) as the collector-output load. The inductor impedance at an oscillation frequency of 1 Megahertz is given on the following page.

$$\begin{aligned}
 X_L &= 2 \pi f L \\
 &= 2(3.14)(10^6)(10 \cdot 10^{-3}) \\
 &= (6.28) 10 \\
 X_L &= 62.8 \text{ K OHMS}
 \end{aligned}$$

The frequency of oscillation is determined by the Resonant Frequency of the Tank Circuit:

$$f = \frac{1}{2 \pi \sqrt{LC}}$$

where $L = L_1 + L_2 + 2M$ (induction of both half of the inductor plus 2 times the mutual inductance (M)).

The Feedback is provided by the "tapped" inductor. Be sure that the proper coil connections are made. The "tap" is not at the center, and the polarity DOT must be connected to the collector. The .25 mfd Capacitors, C_1 and C_2 , are A.C. Coupling capacitors and do not affect frequency. The 1 Megohm Potentiometer adjusts the BIAS.

Procedure:

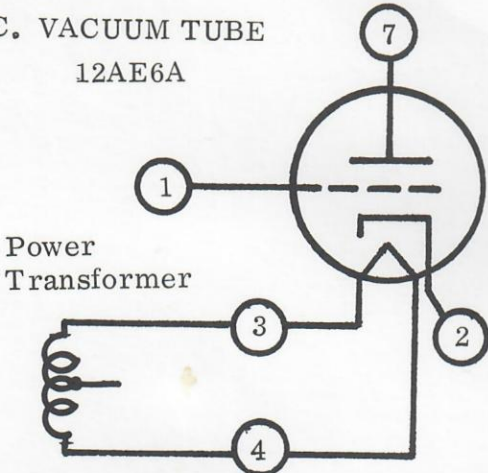
1. Wire the circuit in Figure 2-1. Be sure to connect the proper polarity of the R. F. COIL as shown.
2. Vary the 1 MEGOHM POT to adjust BIAS, observe the Oscillation, and measure the frequency:

OSCILLATING FREQUENCY (C = 330 pfd) =

3. Change the Tank Circuit CAPACITOR from 330 pfd to 0.01 mfd. Measure the Frequency:

OSCILLATING FREQUENCY (C = 0.01 mfd) =

4. Change the capacitor back to $C = 330 \text{ pfd.}$
5. Substitute the following other active components and observe the operation:

ELEMENT	OBSERVATION
A. SILICON TRANSISTOR Q7 	
B. FET TRANSISTOR 	
C. VACUUM TUBE 12AE6A  Power Transformer	
D. PNP TRANSISTOR also change +V1 to -V1 Q3 	

1. Construct the following circuit and observe the operation.
2. Change the capacitor bank to $C = 250 \text{ pF}$.

OBSERVATION	ELEMENT
	A. BIFURCATION TRANSISTOR 
	B. JET TRANSISTOR 
	C. VACUUM TUBE TRANSISTOR 
	D. PNP TRANSISTOR  also change $V_{BE} - V_{CE}$

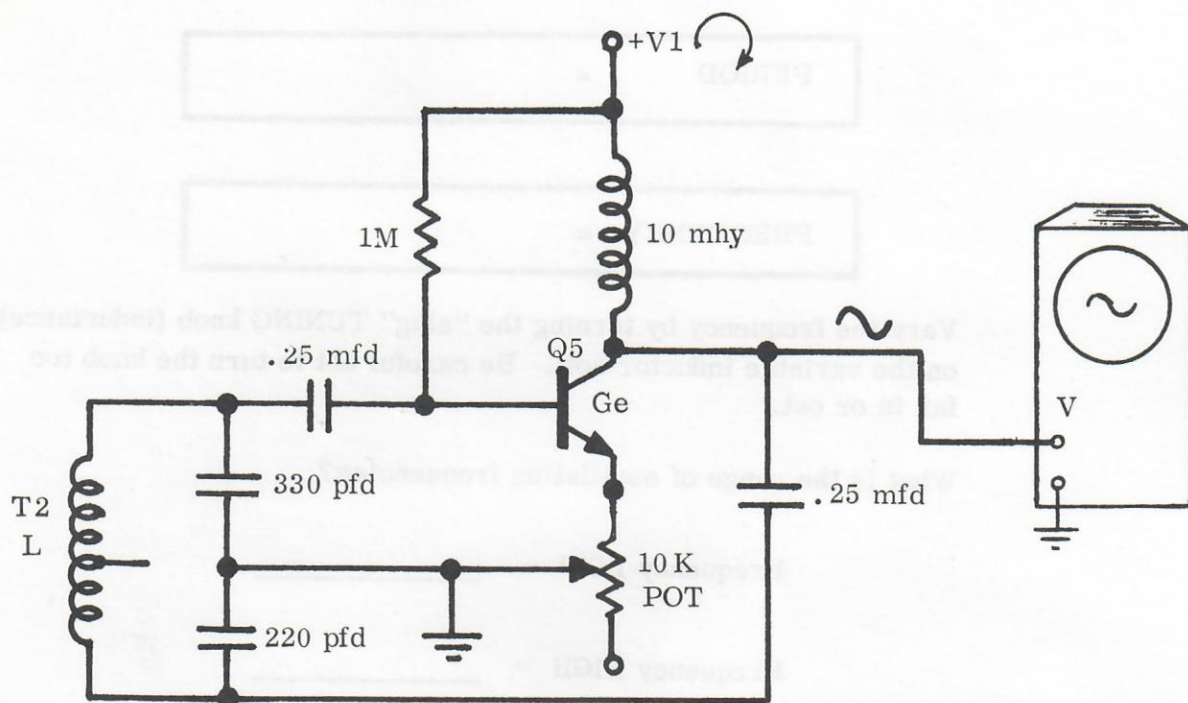


Figure 3 - 1 Colpitts Oscillator

Objective:

You will build and study the Colpitts Oscillator which uses a single inductor and a "tapped" capacitor.

Description:

The Colpitts Oscillator is similar to the Hartley Oscillator except that a single inductor is used in the Tank Circuit but two capacitors are used "as a split-capacitor" for the "feedback" as shown in Figure 3 - 1 above. The 1 MEGOHM resistor is used for bias in this germanium transistor circuit. The two 0.25 mfd capacitors are A.C. Coupling capacitors. The 10K POT adjusts the emitter feedback and the gain.

Procedure:

1. Wire the circuit in Figure 3 - 1.
2. Adjust the 10K POT for an undistorted sine wave as observed on the oscilloscope.
3. Measure the frequency on the oscilloscope if a calibrated time-base (triggered) oscilloscope is used.
MAKE SURE THAT THE 'SCOPE IS IN THE "TIME-CALIBRATED" POSITION.

PERIOD =

FREQUENCY =

Vary the frequency by turning the "slug" TUNING knob (inductance) on the variable inductor coil. Be careful not to turn the knob too far in or out.

What is the range of oscillating frequencies?

Frequency LOW = _____

Frequency HIGH = _____

(Readjust the indicator knob for mid-range after readings.)

4. Measure the frequency using a RADIO (if one is available) held near the Oscillator. Vary the radio tuning dial and listen for a HOWL or SQUEAL. Vary the radio tuning knob for a silent or low tone "null" between a squeal on both sides; left and right. This null is at the oscillator R.F. frequency. What is this measured frequency?

Frequency = _____

You may also hear a squeal at TWICE the frequency (Second Harmonic) and third harmonic and so on. When a null is detected, it is necessary to tune the radio to half this frequency to determine that no other signal is detected and that only the first harmonic or basic frequency is detected.

5. The two 0.25 mfd capacitors are A.C. Coupling capacitors and do not affect frequency.

Substitute 0.01 mfd capacitors for the 0.25 mfd caps and observe that there is no change in frequency.

Does the frequency change? _____

Substitute 10 mfd caps for the 0.25 mfd caps and observe that there is no change in frequency.

Does the frequency change? _____

6. Place your fingers across the transistor "base to ground" and "collector to ground" and "base to collector" and observe that the capacitance of your fingers changes the frequency and operation of the oscillator. What is the effect?

Stray CAPACITANCE	FREQUENCY CHANGE
Base-to-Ground	
Collector-to-Ground	
Base-to-Collector	

Substitute 10 and caps for the 0.22 mfd caps and observe that there is no change in frequency.

Does the frequency change? _____

6. Place your finger across the transistor "base to ground" and "collector to ground" and "base to collector" and observe that the capacitance of your finger changes the frequency and operation of the oscillator. What is the effect?

Frequency Change	Setup Capacitance
	Base-to-Ground
	Collector-to-Ground
	Base-to-Collector

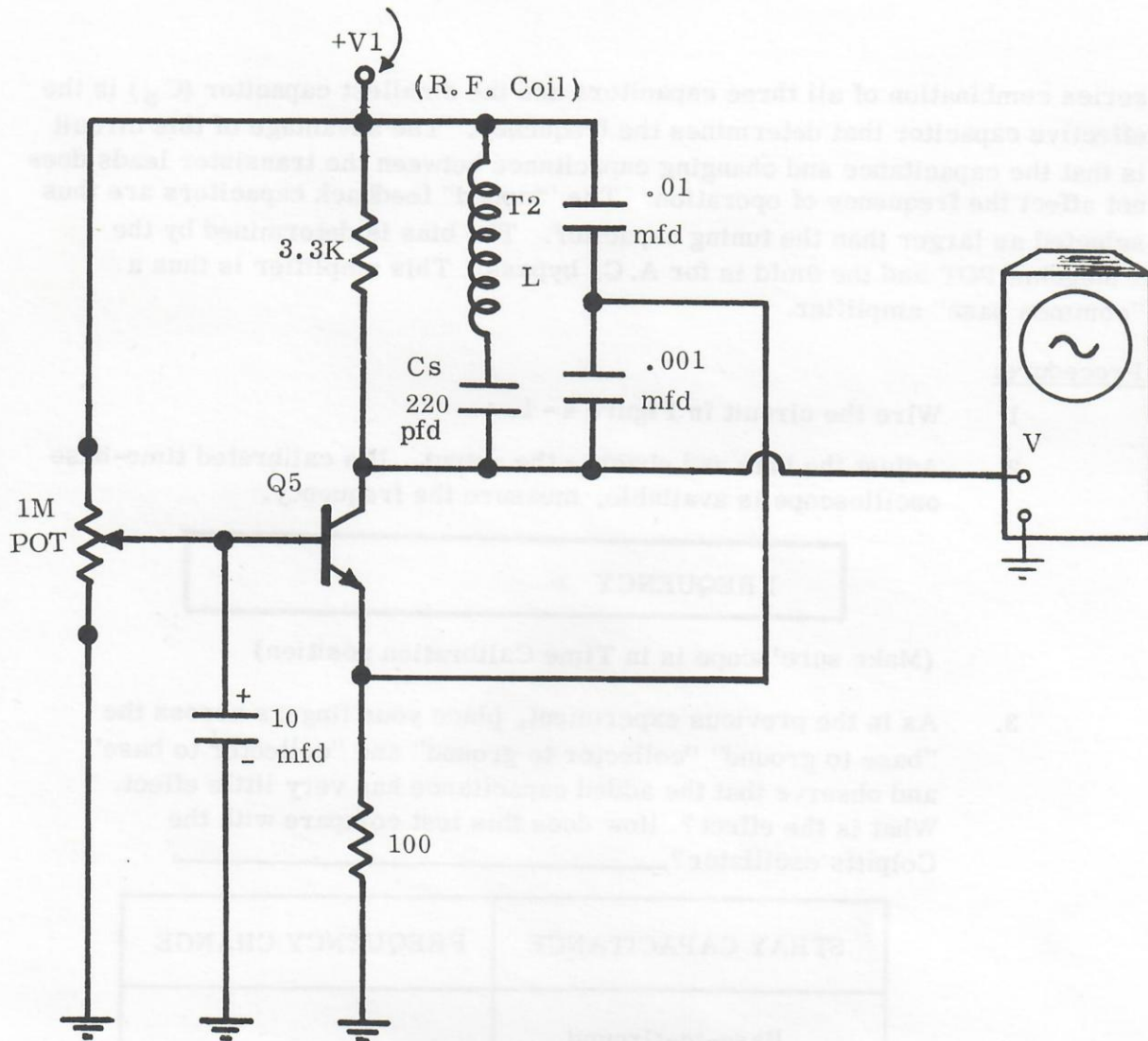


Figure 4 - 1 Clapp Oscillator

Objective:

You will test the CLAPP Oscillator which is a modification of the basic Colpitts Oscillator.

Description:

The Clapp Oscillator is similar to the Colpitts Oscillator with feedback provided by a series or "tapped" capacitor in the Tank Circuit. A smaller Capacitor is added in SERIES with the coil. The effective capacitance is the

series combination of all three capacitors and the smallest capacitor (C_s) is the effective capacitor that determines the frequency. The advantage of this circuit is that the capacitance and changing capacitance between the transistor leads does not affect the frequency of operation. The "tapped" feedback capacitors are thus selected as larger than the tuning capacitor. The bias is determined by the 1 Megohm POT and the 0mfd is for A.C. bypass. This amplifier is thus a "common base" amplifier.

Procedure:

1. Wire the circuit in Figure 4 - 1.
2. Adjust the bias and observe the output. If a calibrated time-base oscilloscope is available, measure the frequency.

FREQUENCY =

(Make sure scope is in Time Calibration position)

3. As in the previous experiment, place your fingers across the "base to ground" "collector to ground" and "collector to base" and observe that the added capacitance has very little effect. What is the effect? How does this test compare with the Colpitts oscillator? _____

STRAY CAPACITANCE	FREQUENCY CHANGE
Base-to-Ground	
Collector-to-Ground	
Base-to-Collector	

4. Place your fingers across the 220 mfd tuning capacitor. What is the effect?
5. Substitute the Silicon Transistor; Q7. Does the circuit work? _____
6. Substitute the FET Transistor. Does the circuit work? _____
Not all circuits will operate for Transistors, FETs and Tubes. The requirements are different for bias; the element gains and impedances are different, and thus the component values and even circuit layouts are generally different.

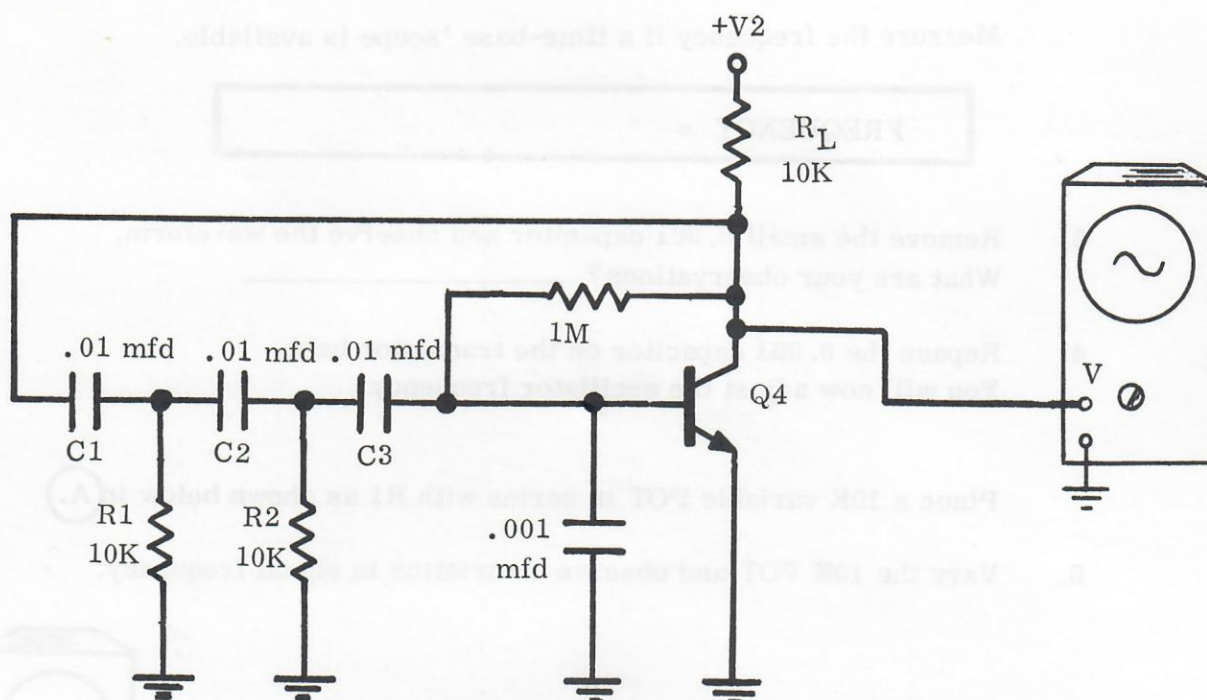


Figure 5-1 Phase Shift Oscillator

Objective:

You will build and test a Phase Shift Oscillator.

Description:

The requirement for oscillation is feedback with a positive gain of 1. Single stage amplifiers have a negative gain and an inversion is required from the output to the input. An inversion for a sine wave is a time shift of half a cycle or a phase shift of 180 degrees. An RC network results in a phase shift. Three series or cascaded RC networks are used with a transistor amplifier to result in a 180 degrees phase shift at the frequency of oscillation. All components including the load resistor and bias resistor affect the phase shift. There is attenuation in the phase shift circuit, and the amplifier gain must be adequate to result in a total "loop-gain" of 1. A collector feedback bias circuit is used and no bias adjustment is necessary. Depending on the transistor gain or beta, different bias resistors would be used; 470K or 2M or 4.7M. The small capacitor (.001 mfd) is used to suppress high frequency oscillation that would occur because of phase shifts at higher frequencies.

Procedure:

1. Wire the circuit in Figure 5-1.
2. Observe the output sine wave signal.
Does the circuit operate as an oscillator? _____

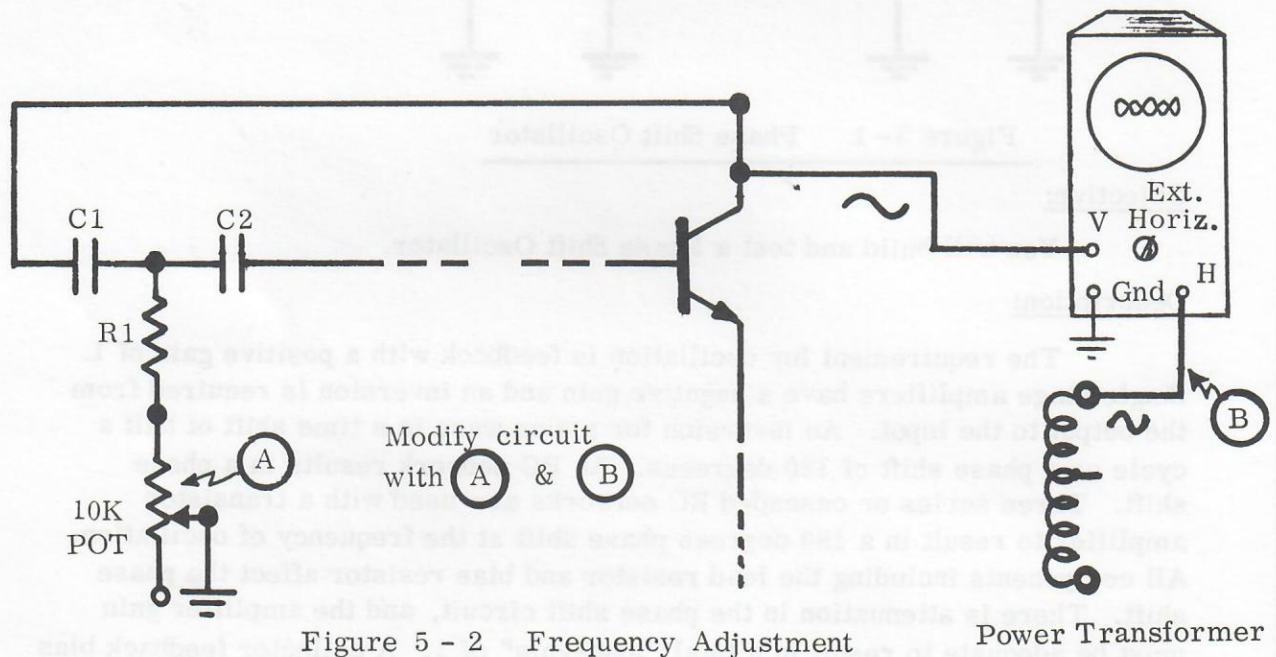
Measure the frequency if a time-base 'scope is available.

FREQUENCY =

3. Remove the small 0.001 capacitor and observe the waveform. What are your observations? _____
4. Repace the 0.001 capacitor on the transistor base. You will now adjust the oscillator frequency.

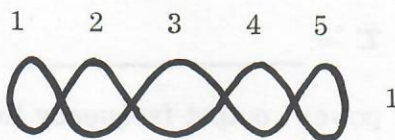
Place a 10K variable POT in series with R1 as shown below in (A).

5. Vary the 10K POT and observe a variation in signal frequency.



6. Add the Connection to the Oscilloscope Horizontal Input as shown at (B) in Figure 5-2. Set the scope on X-Y display to generate a Lissajous Pattern.

Vary the 10K POT to result in a 300 Hertz signal as given by the following pattern (5 to 1).



Lissajous Pattern (5:1)

The frequency is then 5×60 Hertz or 300 Hertz. Can you obtain this frequency? Can you obtain any other frequencies (6 to 1 or 4 to 1)? You may want to reduce R1 from 10K to 3.3K to increase the frequency.

7. The Oscillators generate Sinusoidal signals which are used in many communications applications. The frequency (f_R) is determined by a Capacitance-Inductance resonance in a Tank (Parallel) or Series Circuit and is given by:

$$f_R = \frac{1}{2\pi\sqrt{LC}}$$

Other oscillators such as this phase shift oscillator have a frequency determined by Resistance-Capacitance (RC) circuits. These networks have an associated time constant. For a simple RC circuit, the time constant is:

TIME CONSTANT = τ (Greek Letter)

$\tau = RC$
 where τ is in seconds
 R is in OHMs
 C is in Farads

Calculate the time constant for

R = 10 kilohms
 C = 0.01 microfarads

$$\tau = RC \quad \text{seconds}$$

$$\tau = \underline{\hspace{2cm}}$$

The "half power" output frequency for a simple RC stage is given by:

$$f_c = \frac{1}{2 \pi RC}$$

where f_c is in Hertz.

Calculate this frequency for:

$$R = 10K$$

$$C = 0.01 \text{ mfd}$$

$$f_c = \frac{1}{2 \pi RC}$$

$$f_c = \underline{\hspace{2cm}} \text{ hertz}$$

The phase shift circuit is not a simple RC network and one network affects the others. An approximation for this phase shift oscillator frequency is about $1/3$ of the above calculated frequency. What is the predicted oscillator frequency (f_p) using $1/3 f_c$?

$$f_p = \underline{\hspace{2cm}} \text{ hertz}$$

How does this compare with the actual phase-shift oscillator frequency?

Other Oscillators using Resistors and Capacitors for frequency control include the R.C. OSCILLATOR, WEIN-BRIDGE OSCILLATOR, and TWIN-TEE OSCILLATOR were RC components are used in very sensitive circuits to accurately control frequency. CRYSTALS are used in oscillators to accurately control a single fixed frequency. In very high frequency oscillators, the wires themselves act as inductors and capacitors and affect frequencies.

Non-sinusoidal oscillators include square-waves and pulses and ramps, and these are covered in the PULSE GENERATION and WAVESHAPING series of experiments.

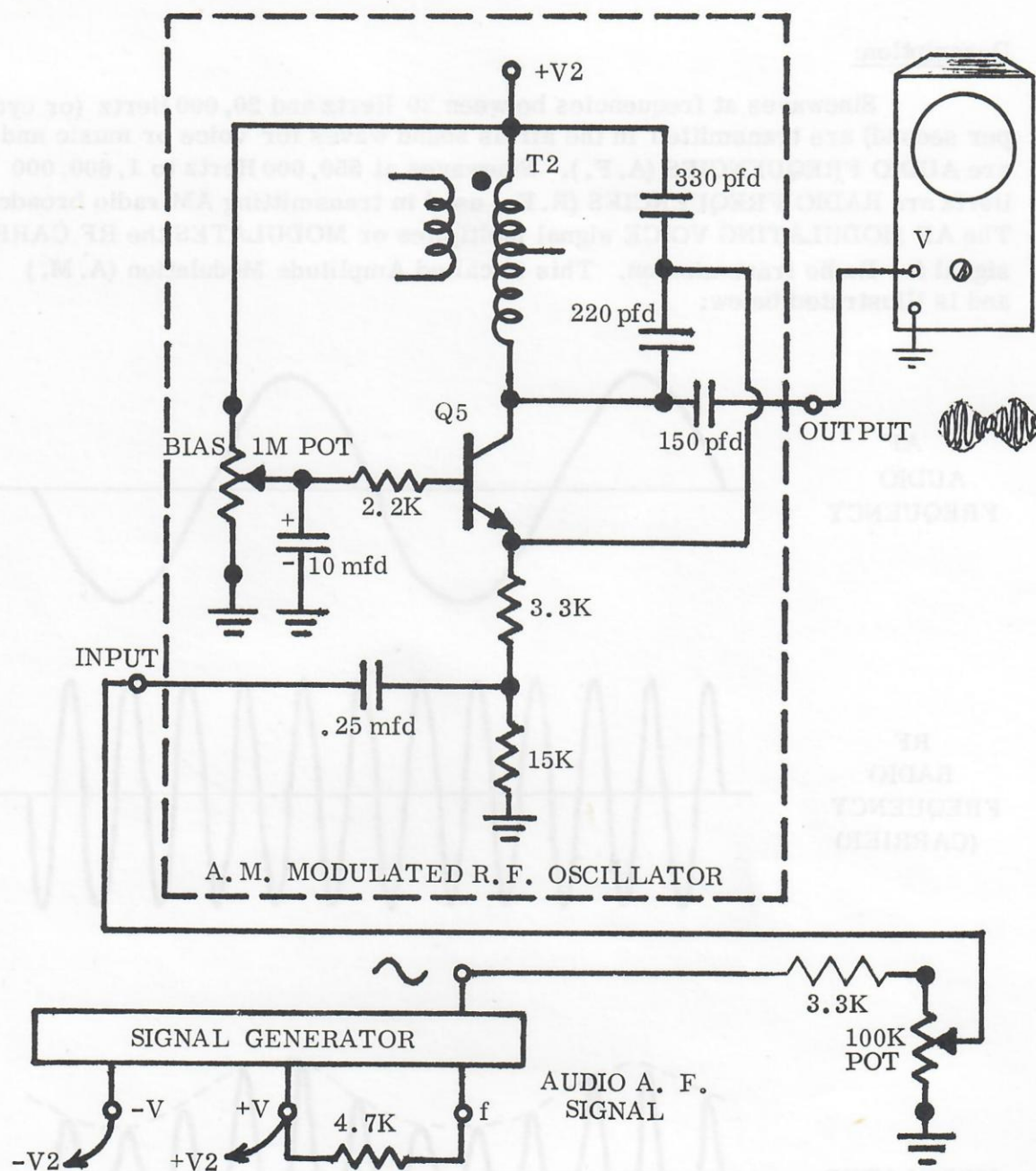


Figure 6 - 1 Amplitude Modulated Oscillator

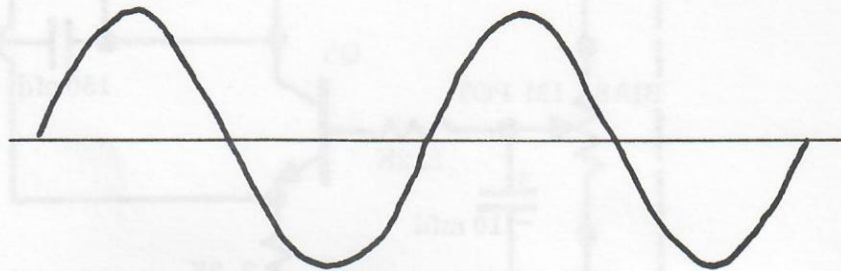
Objective:

You will insert an Audio Frequency Signal (A.F.) in a Colpitts Oscillator circuit to control the amplitude of the Radio Frequency (R.F.) signal. The result is an Amplitude Modulated waveform which can be used to transmit radio broadcast signals.

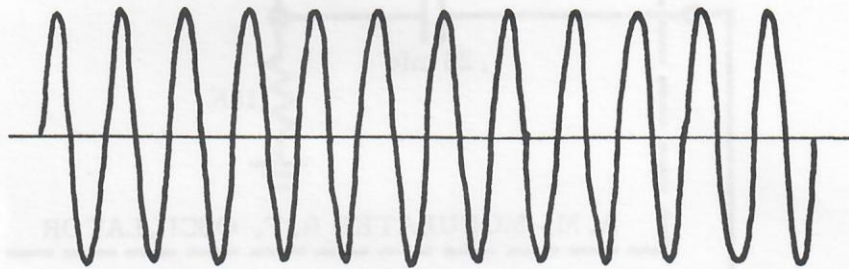
Description:

Sinewaves at frequencies between 20 Hertz and 20,000 Hertz (or cycles per second) are transmitted in the air as sound waves for voice or music and are AUDIO FREQUENCIES (A.F.). Sinewaves at 550,000 Hertz to 1,600,000 Hertz are RADIO FREQUENCIES (R.F.) used in transmitting AM radio broadcasts. The AF MODULATING VOICE signal multiplies or MODULATES the RF CARRIER signal for Radio transmission. This is called Amplitude Modulation (A.M.) and is illustrated below:

AF
AUDIO
FREQUENCY



RF
RADIO
FREQUENCY
(CARRIER)



AM
MODULATED
CARRIER

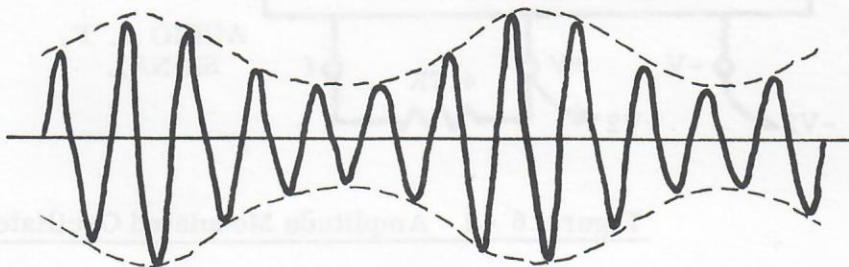


Figure 6 - 1 Amplitude Modulated Signals

Other higher radio frequencies are used for different communications applications in FM Radio, Television, Marine and Aircraft Radio, and C.B. Radio, and will be discussed later.

The amount of amplitude modulation is given by the PERCENTAGE MODULATION which varies from 0% (no modulation) to 100%, which is full modulation. Over 100% is Over Modulation which results in distorted sounds. This is illustrated below:

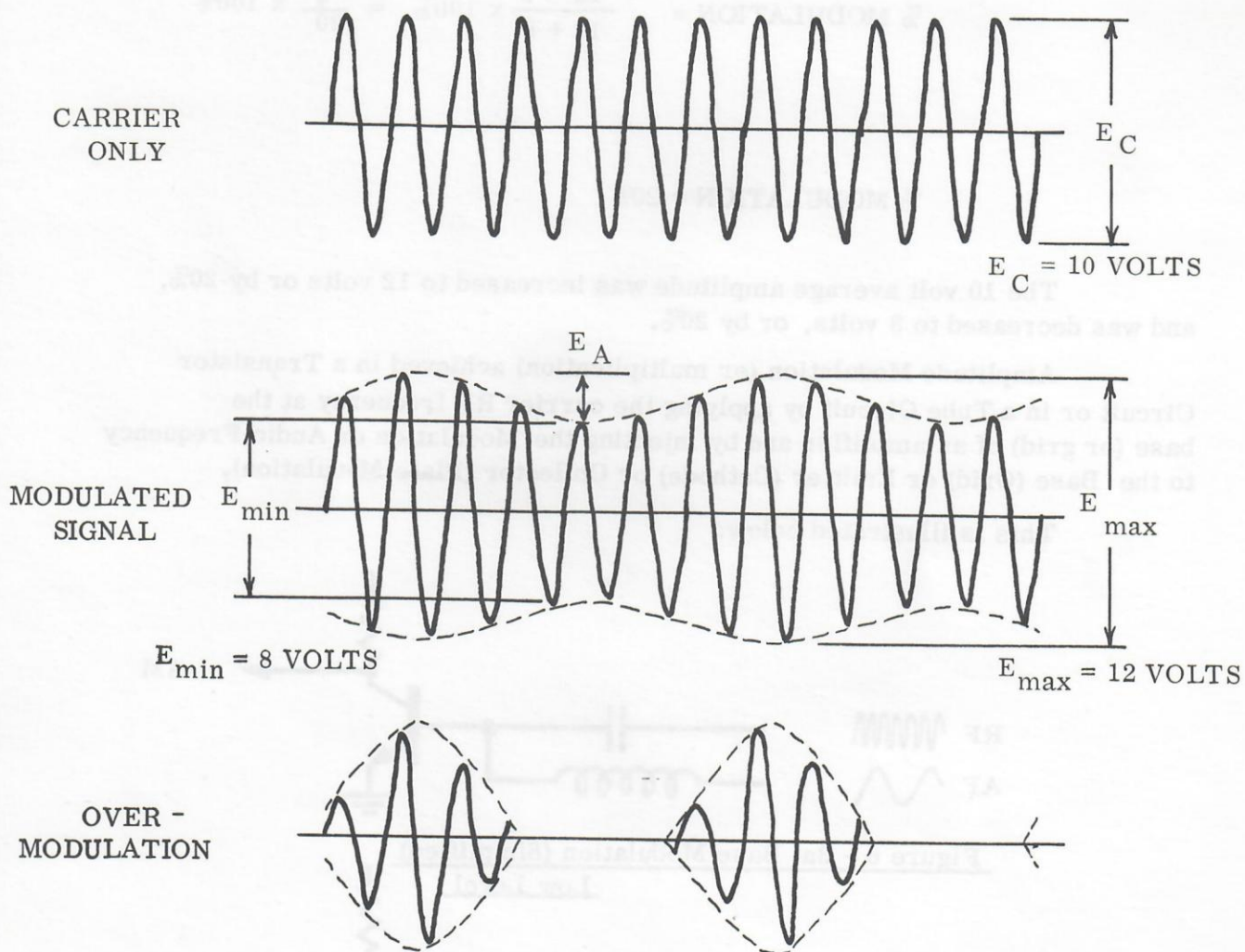


Figure 6 - 2 Percentage Modulation

The PERCENTAGE MODULATION is given by the ratio of the difference in maximum $E_{\max}$ and minimum $E_{\min}$ signals to the unmodulated carrier E_C .

$$\text{PERCENTAGE MODULATION} = \frac{E_A}{E_C} \times 100\%$$

(E_c is also the average between the max. and min. signals.) and is given by:

$$\% \text{ MODULATION} = \frac{(E_{\max} - E_{\min})}{(E_{\max} + E_{\min})} \times 100\%$$

For the problem shown above, the % MODULATION is:

$$\% \text{ MODULATION} = \frac{12 - 8}{12 + 8} \times 100\% = \frac{4}{20} \times 100\%$$

$$\% \text{ MODULATION} = 20\%$$

The 10 volt average amplitude was increased to 12 volts or by 20%, and was decreased to 8 volts, or by 20%.

Amplitude Modulation (or multiplication) achieved in a Transistor Circuit or in a Tube Circuit by applying the carrier RF frequency at the base (or grid) of an amplifier and by injecting the Modulation or Audio Frequency to the Base (Grid) or Emitter (Cathode) or Collector (Plate Modulation).

This is illustrated below:

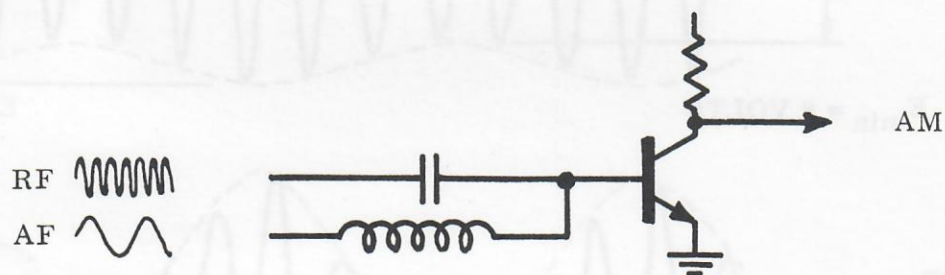


Figure 6 - 3a Base Modulation (Simplified)
Low Level

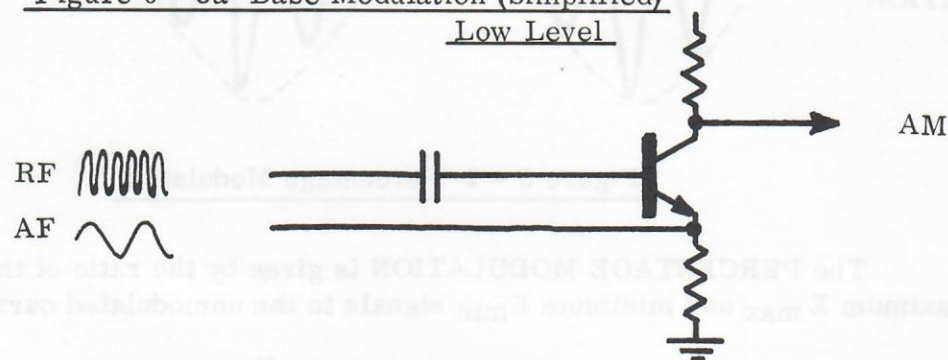


Figure 6 - 3b Emitter Modulation (Simplified)

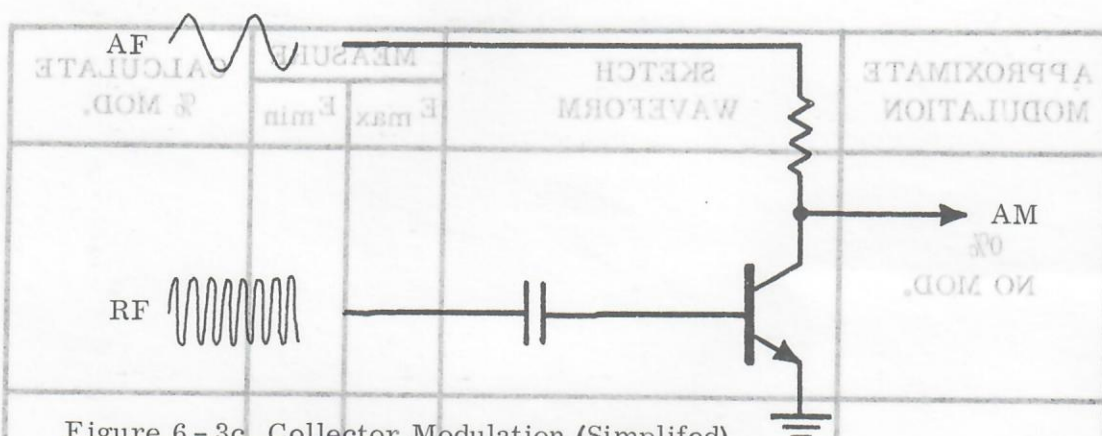


Figure 6 - 3c Collector Modulation (Simplified)
High Level

An A.M. Transmitter generally has various sections or stages; an Oscillator, or Audio Amplifier, a Power Supply, a Modulator, and a Power Output Amplifier. Modulation can be achieved at the final Power Output Amplifier called HIGH LEVEL MODULATION or at some earlier stage called LOW LEVEL MODULATION.

This experiment uses a transistor Colpitts Oscillator to generate the R.F. Frequency. A.M. Modulation is performed directly on the Oscillator and there is no output power stage. An Emitter Modulation method is employed. Although the experiment circuit shown in Figure 6 - 1 has very low output power, it is used to demonstrate the principles of Amplitude Modulation. Later experiments will demonstrate complete transmitter systems.

Procedure:

1. Wire the Colpitts Oscillator Circuit in Figure 6 - 1. A large emitter resistor is used to provide audio modulation (linear) in the emitter circuit. The Signal Generator provides the Audio Frequency signal and the 10K Potentiometer is used to vary the modulation amplitude or percentage modulation.
2. Adjust the 100K Potentiometer for a modulation of 0%; some mid-value at approximately 20% and 50% modulation; 100% modulation; and overmodulation. Sketch the various modulated R.F. Signals on the following page and measure the minimum amplitudes on the oscilloscope.
3. Calculate the percent modulation using E_{max} and E_{min} and enter the results in the chart on the following page:

3. Calculate the Percent Modulation using E_{max} and E_{min} and enter the results in the above chart.

APPROXIMATE MODULATION	SKETCH WAVEFORM	MEASURE		CALCULATE % MOD.
		$E_{\max}$	$E_{\min}$	
0% NO MOD.				
20%				
50%				
100%				
OVER- MODULATION				

3. Calculate the Percentage Modulation using $E_{\max}$ and $E_{\min}$ and enter the results in the above chart.

Additional Description: AM BANDWIDTH

The RF carrier radio frequency is f_R . The AF modulating voice frequency is f_A . The A.M. Modulated signal generally results in a wide range of frequencies as indicated in the sketch below:

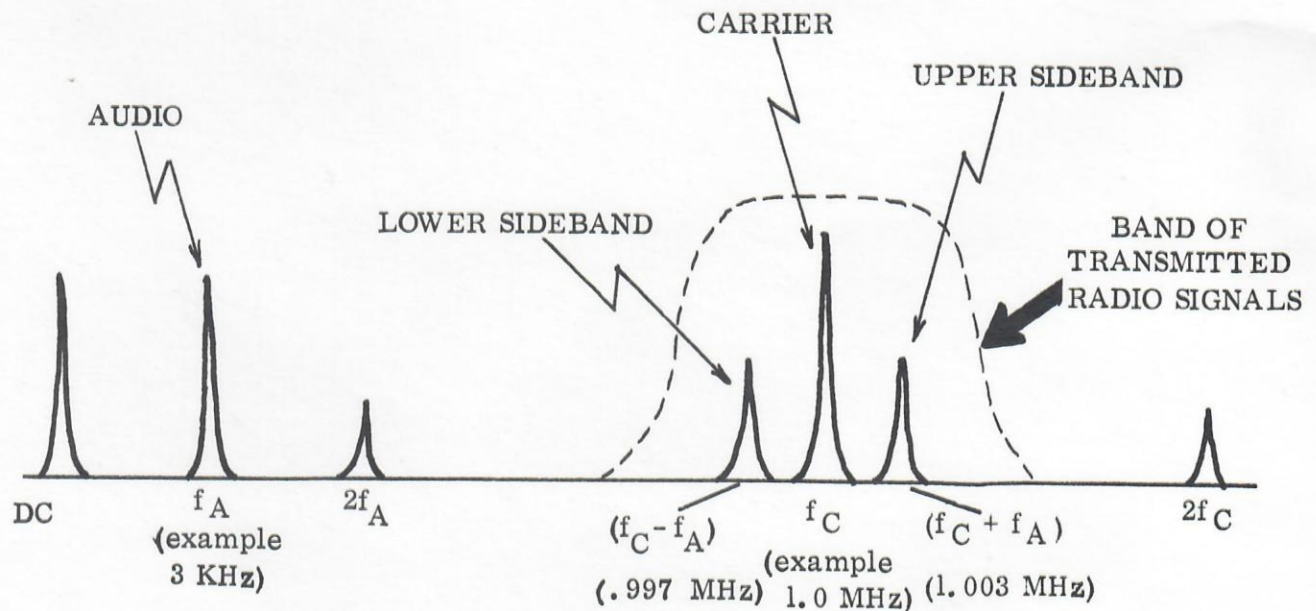


Figure 6 - 4 Composite Signal - Frequency Graph
AM Modulated Signal

A D.C. voltage or offset is often part of the output; the original Audio Signal is still present (f_A); a "harmonic" or 2 times f_A is present; the carrier frequency (f_C) is accompanied by 2 "side-bands": ($f_C - f_A$: lower and $f_C + f_A$: upper); and harmonics of the carrier frequency ($2f_C$) and perhaps others ($3f_C$) and so on, are present together with their upper and lower sidebands. The only output of interest is f_C and the sidebands. This is the transmitted radio signal, and the others are eliminated by using a filter at the transmitter output.

The standard AM broadcast band is from 535 KHz to 1605 KHz. Stations or channels are 10 KHz wide (i.e. the audio is up to 5KHz) with 10 KHz separation between channels. Percentage modulation is to be between 85% and 95%. The

AM Radio thus has a Carrier Frequency and a Bandwidth of 10 KHz which includes the upper and lower sidebands for an audio signal of up to 5 KHz. Any higher frequency audio signal would cause interference with another station and is not permitted.

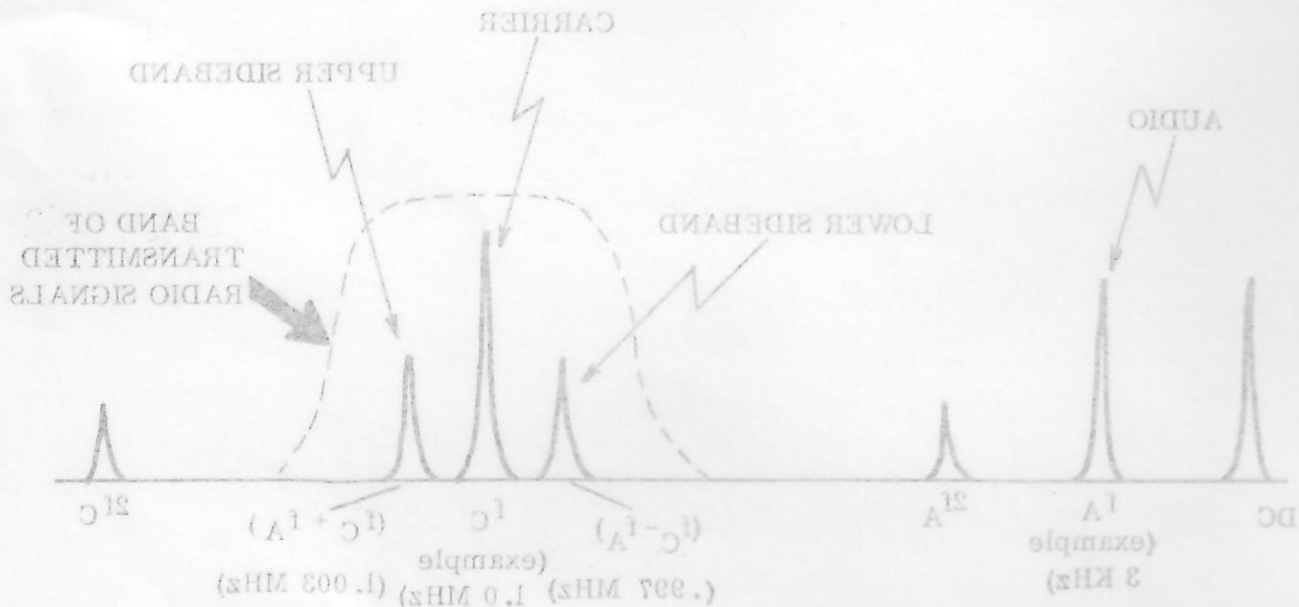


Figure 6-4 Composite Signal - Frequency Graph
AM Modulated Signal

A D.C. voltage or offset is often part of the output; the original Audio Signal is still present (1A); a "harmonic" or 2 times 1A is present; the carrier frequency (1C) is accompanied by 2 "side-bands": (1C - 1A : lower and 1C + 1A : upper); and harmonics of the carrier frequency (2fC) and perhaps others (3fC) and so on, are present together with their upper and lower sidebands. The only output of interest is 1C and the sidebands. This is the transmitted radio signal, and the others are eliminated by using a filter at the transmitter output.

The standard AM broadcast band is from 535 KHz to 1605 KHz. Stations or channels are 10 KHz wide (i.e. the audio is up to 5KHz) with 10 KHz separation between channels. Percentage modulation is to be between 85% and 95%. The

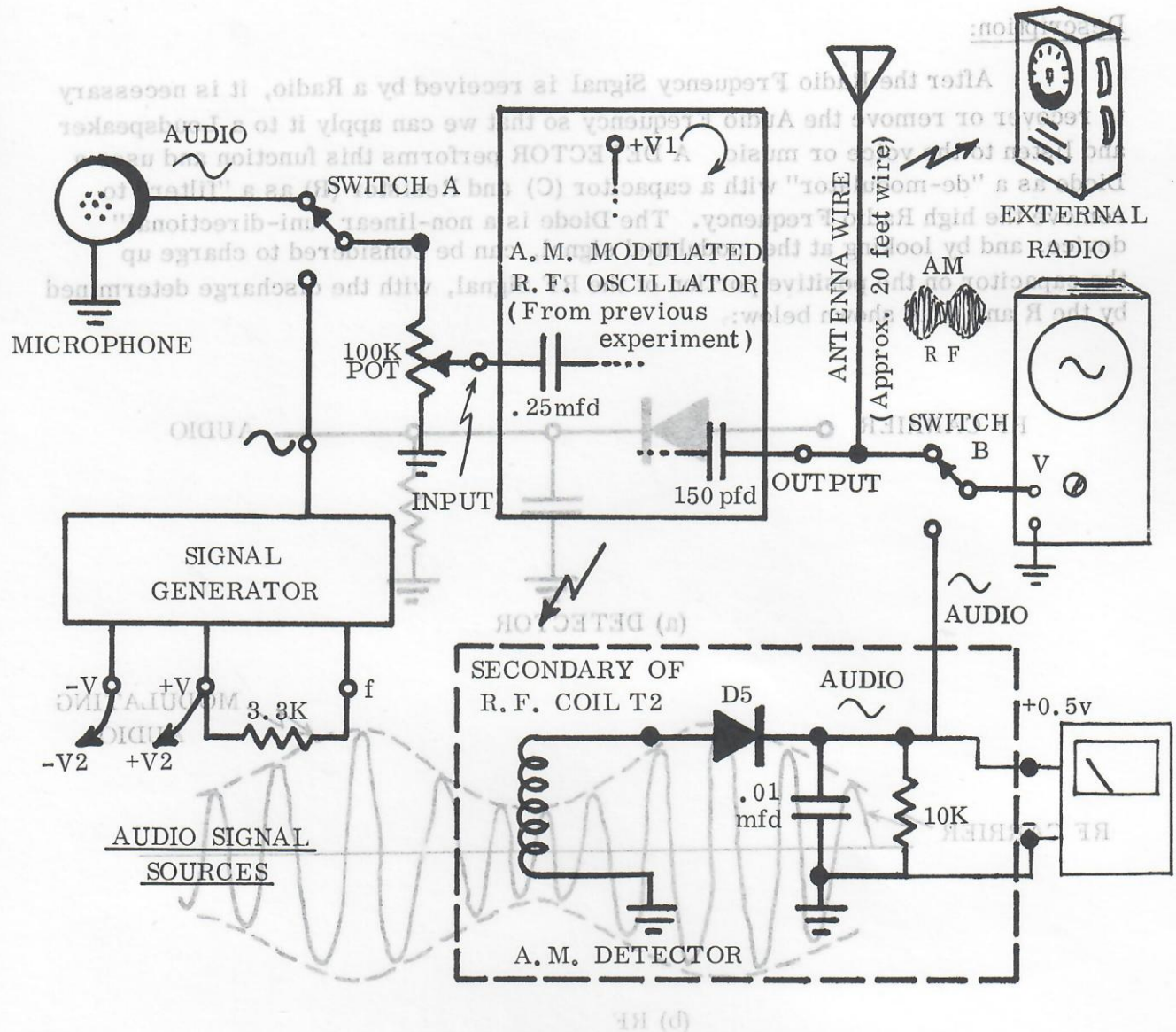


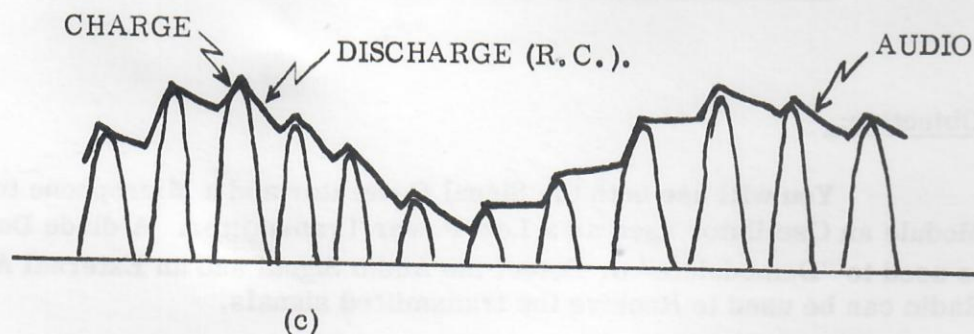
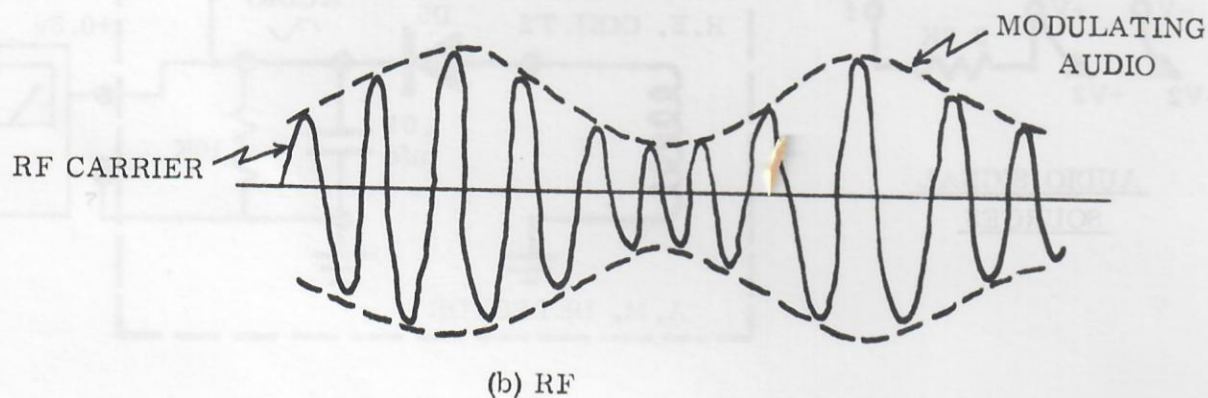
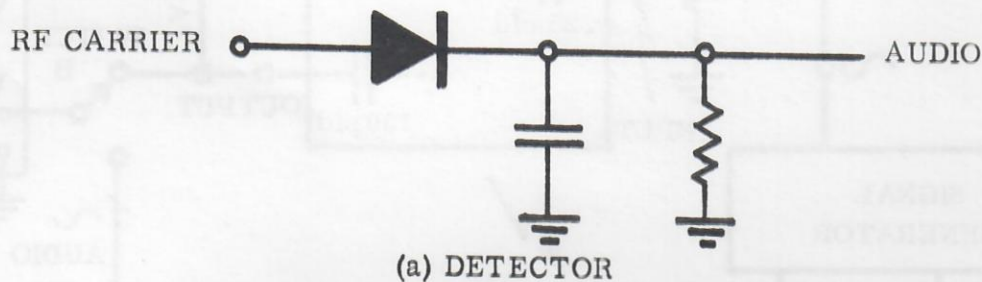
Figure 7 - 1 A.M. Broadcaster and A.M. Detector

Objective:

You will use both the Signal Generator and a Microphone to A.M. Modulate an Oscillator used as a Low Power Transmitter. A diode Detector is used to "Demodulate" or Detect the Audio Signal and an External A. M. Radio can be used to Receive the transmitted signals.

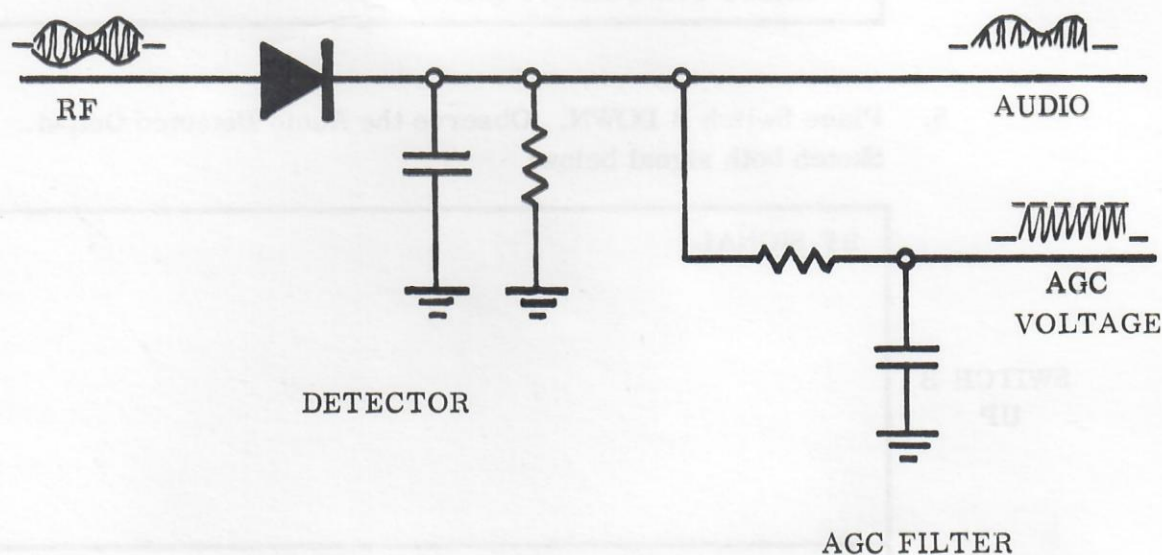
Description:

After the Radio Frequency Signal is received by a Radio, it is necessary to recover or remove the Audio Frequency so that we can apply it to a Loudspeaker and listen to the voice or music. A DETECTOR performs this function and uses a Diode as a "de-modulator" with a capacitor (C) and Resistor (R) as a "filter" to remove the high Radio Frequency. The Diode is a non-linear "uni-directional" device, and by looking at the modulated signal, can be considered to charge up the capacitor on the positive portion of the RF Signal, with the discharge determined by the R and C as shown below:



The output of the Detector is thus the original Audio Signal plus some "ripple" at the carrier frequency. This "ripple" is at such a high frequency as not to be heard or even reproduced by a loudspeaker.

An additional R-C low pass filter can be connected to the detector to provide a D.C. Voltage equal to the average of the audio signal. This can be used to measure the level of the received radio signal and can be applied to adjust the gain of the radio to result in a generally constant audio sound level, even at different power and voltages, received by the radio from different stations. This output is called an Automatic Gain Control or AGC signal. This circuit is illustrated below:



The experiment diagram shown in Figure 7 - 1 uses the AM Modulated Colpits Oscillator from the previous experiment. The audio input is selected as coming from the Microphone or from the Signal Generator sinewave output by using Switch A. A long wire is connected to the output of the Oscillator to act as a Radio Transmitting Antenna. Switch B is used to select the Oscilloscope presentation either as the Modulated RF Signal or as the Detected Audio Signal. The AGC Signal is monitored on the meter.

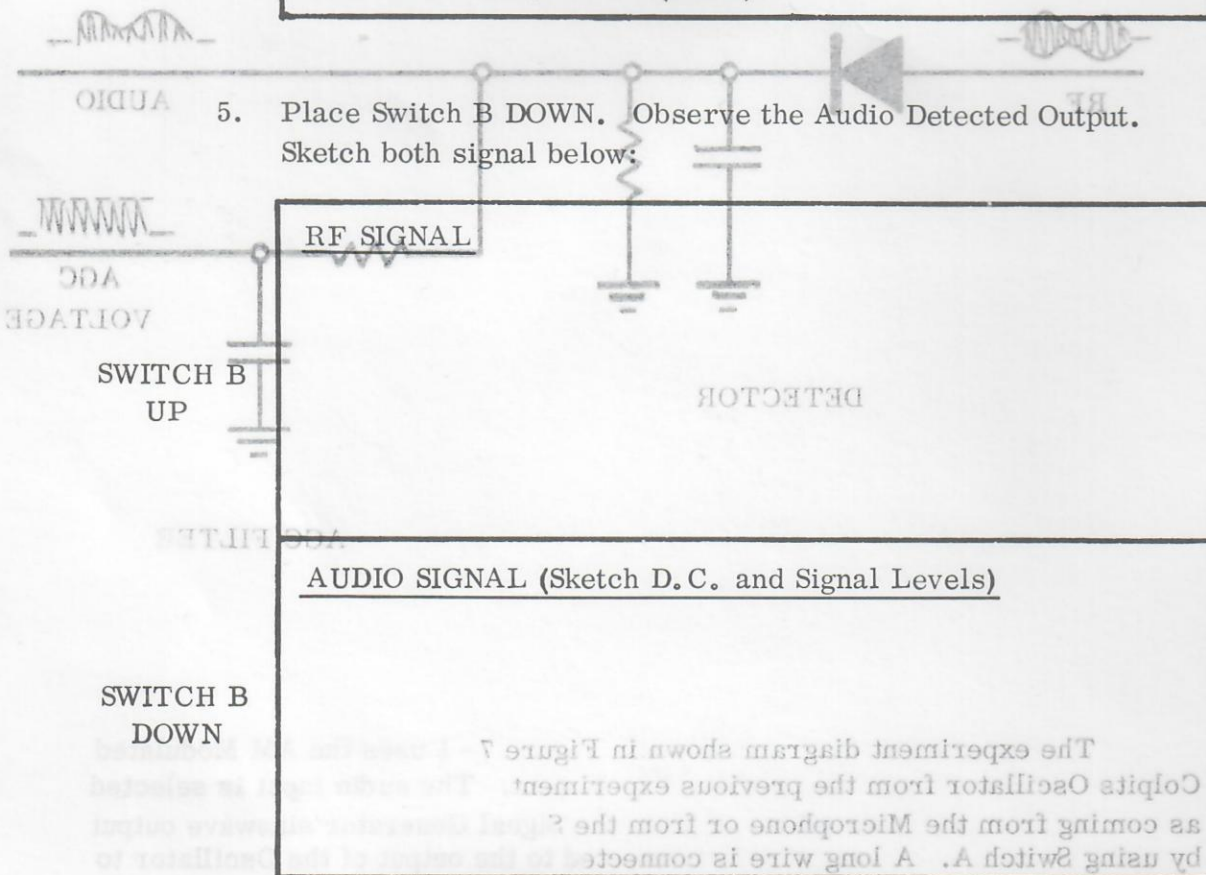
Procedure:

1. Wire the circuit as shown in Figure 7 - 1. Set +V1 at maximum-clockwise-voltage. Connect a long antenna wire as shown. Use an external Radio if one is available.
2. Set Switch A DOWN. The Signal Generator sinewave output is now connected to the Modulator.

3. Set Switch B UP. The Oscilloscope monitors the Modulated Output. Adjust the 1M Bias POT in the Oscillator circuit for an output RF Signal. Adjust the 100K POT for Audio Modulation of over 50%.

4. Tune the Radio, if one is available, until the Signal Generator Tone is heard. The Radio is now tuned at proper RF Carrier (or perhaps at a higher harmonic of the frequency). Tune the Radio to the lowest "station" that receives the tone. What is the frequency as determined by the Radio Dial Setting.

RADIO FREQUENCY (DIAL) =



6. Set Switch A UP. Speak into the Microphone and observe the Detected Audio Signal on the Oscilloscope and the Listen to the Broadcasting over the Radio. If the transmitting frequency interferes with a radio station, change the transmitting oscillator

frequency by adjusting the Tuning KNOB on the R.F. Coil to a clear channel. Then retune the Radio. This low power transmitter has very little range, but demonstrates the operating principle of radio A.M. Modulation and Detection.

7. The AGC Signal provides a DC voltage proportional to the signal strength. For various settings of signal strength, read the AGC Voltage output on the meter. Enter the data below. The R.F. Signal strength is varied by reducing the voltage at +V1. Observe the R.F. Signal (Switch B UP).

ADJUST R.F. SIGNAL STRENGTH	AGC D.C. VOLTAGE (Meter)
+V1 to maximum	
+V1 lower	
+V1 medium	
+V1 very low	

frequency of the signal the Tuning Knob on the R.F. Coil is a
 most essential. It is used to tune the Radio. This low power transmitter
 has very little range, but demonstrates the operating principle of
 radio A.M. Modulation and Detection.

The Audio Signal provides a DC voltage proportional to the signal
 strength. For various settings of signal strength, read the A.C.
 Voltage across the meter. Enter the data below. The R.F.
 signal strength is varied by varying the voltage at V.I. (Power
 the R.F. signal (Source B.V.T.).

ADJUST R.F. SIGNAL STRENGTH	A.C. R.M.S. VOLTAGE (meter)
Very Low	
Low	
Medium	
High	

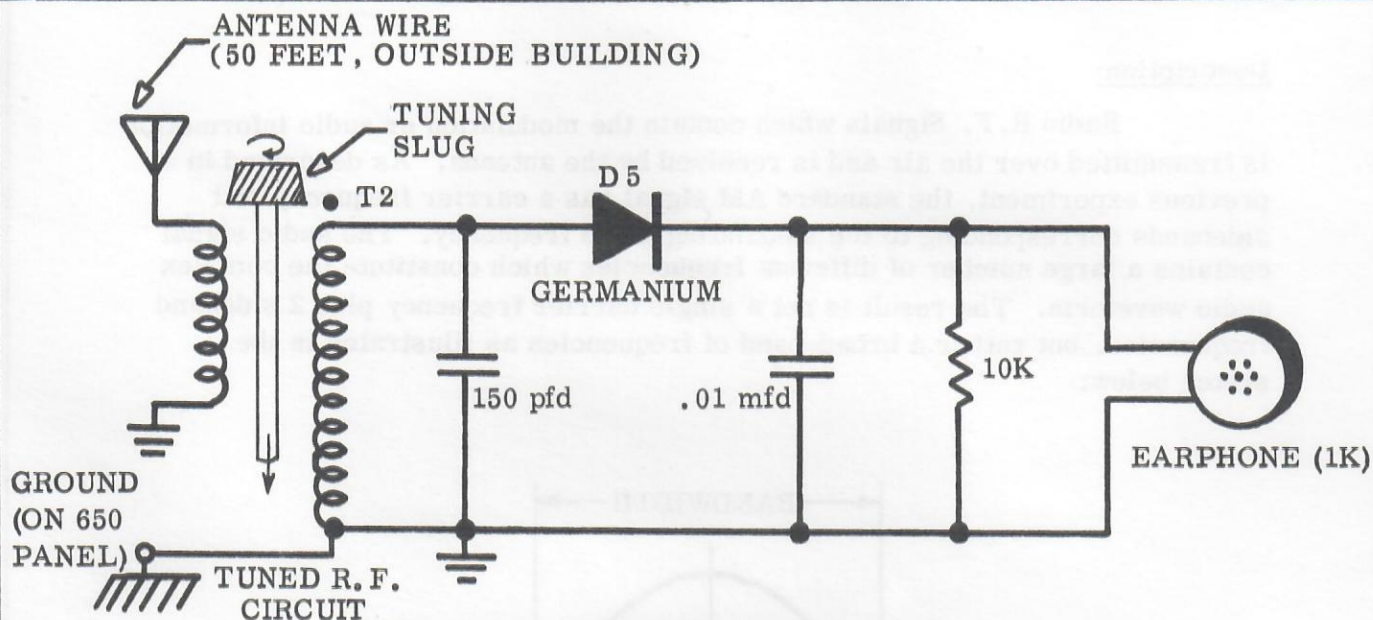


Figure 8-1 Diode A.M. Radio Detector

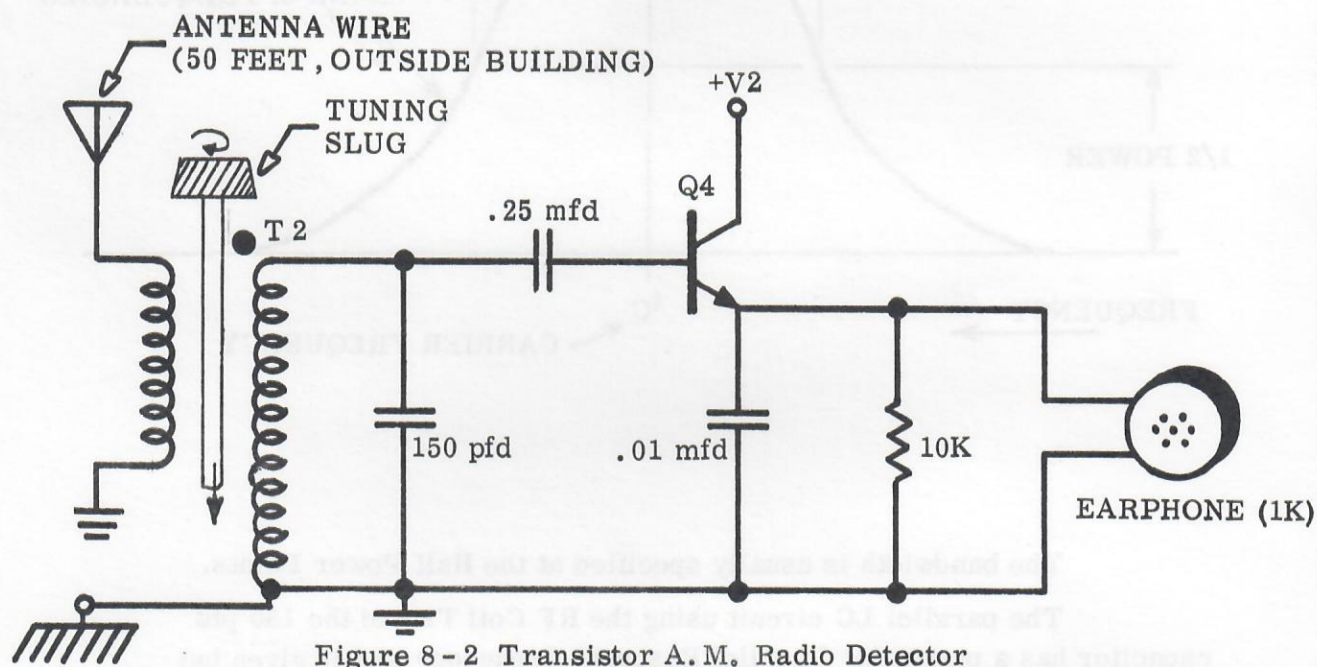


Figure 8-2 Transistor A.M. Radio Detector

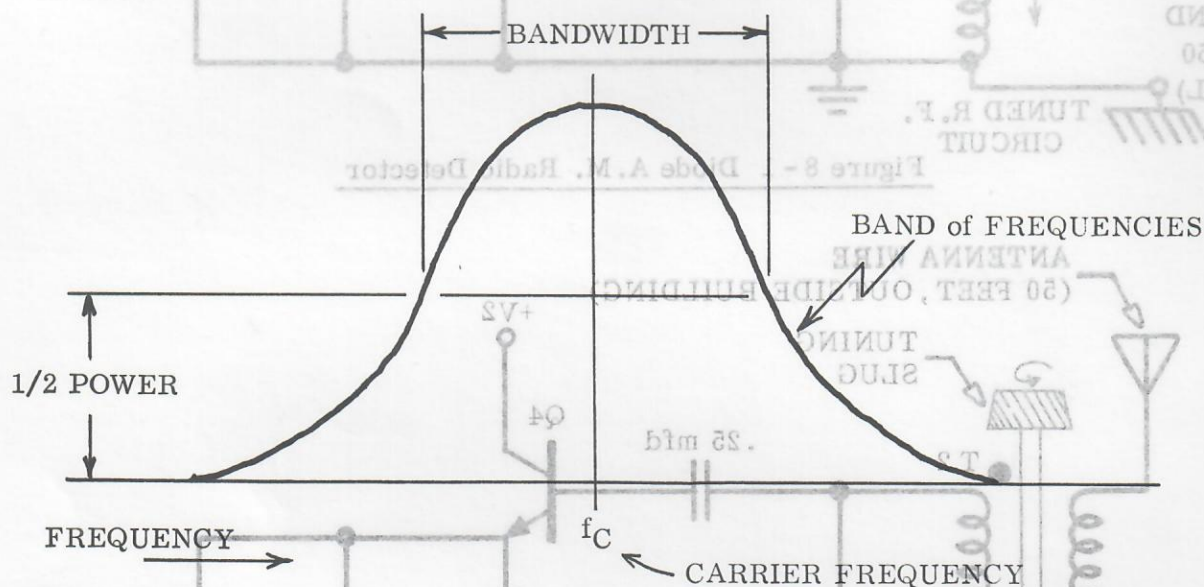
Objective:

You will connect an ANTENNA to a Parallel Resonant Circuit which is tuned to the Radio Broadcast Band frequencies. You will connect an A.M. Diode Detector to the Tuned Circuit and then connect an Earphone. You will install a simple wire antenna and listen to local radio stations.

You will connect a Transistor to the Tuned Circuit and use the Transistor base-emitter junction diode as a Detector. This circuit provides a high input impedance to the Tuned Circuit to reduce loading by the Earphone and this results in an increased volume.

Description:

Radio R.F. Signals which contain the modulation or audio information is transmitted over the air and is received by the antenna. As described in a previous experiment, the standard AM signal has a carrier frequency and sidebands corresponding to the modulating audio frequency. The audio signal contains a large number of different frequencies which constitute the complex audio waveform. The result is not a single carrier frequency plus 2 sideband frequencies, but rather a broad-band of frequencies as illustrated in the sketch below:



The bandwidth is usually specified at the Half Power Points.

The parallel LC circuit using the RF Coil T2 and the 150 pfd capacitor has a particular Parallel Resonant Frequency and is given by:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

The antenna is connected to a lower "tap" on the inductor which results

in an auto-transformer effect in the resonant or "tank" circuit to increase signal level. The only radio signal "received" by this resonant circuit is the one corresponding to the resonant frequency.

The simplest form of radio receiver is as shown in Figure 8-1. This circuit is called a "Tuned Radio Frequency" Receiver or TRF Receiver. The LC Tuning Circuit is adjusted to the resonant frequency of the desired station. The Demodulator or Detector provides the Audio signal, and the Earphone or headset enables us to hear the radio.

Another version uses a Transistor as shown in Figure 8-2. The base to emitter junction acts as the demodulating diode. The transistor provides a high input impedance at the base and reduces loading of the resonant circuit, resulting in a higher signal and a louder audio volume.

Procedure:

1. Wire the simple TRF Radio in Figure 8-1. Connect a long (over 20 feet) antenna outside of the building. Connect the ground to the "panel ground" which is connected to the master electrical ground if a 3 wire socket is used.
2. Listen to the radio and vary the tuning (R.F. Coil Knob) to receive different stations. List some stations that you receive:

RADIO STATION	FREQUENCY	COMMENTS

3. Change the radio receiver to the Transistor version of Figure 8-2 by removing the 2 wires from the diode, and substituting the transistor base-emitter junction. Then connect the collector to +V2 voltage.
4. How does the volume compare to the diode detector circuit?
5. List some radio stations that you receive. How many additional stations can you receive? What is the frequency tuning range?

[illegible]

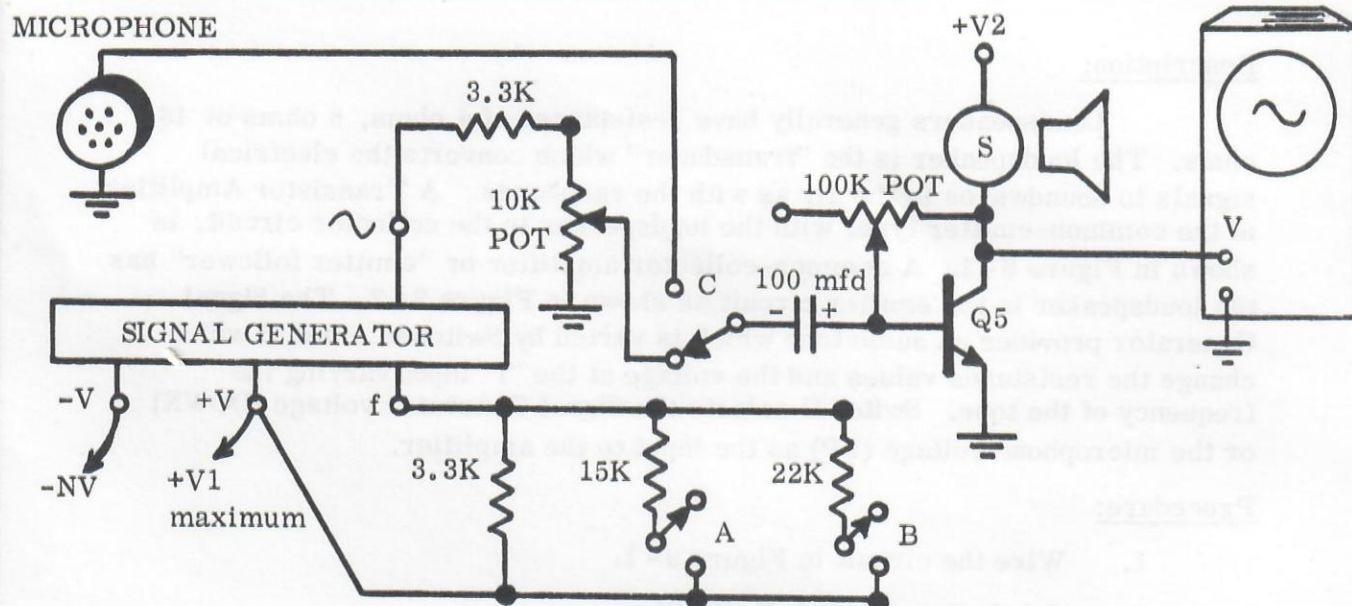


Figure 9-1 Common Emitter Amplifier

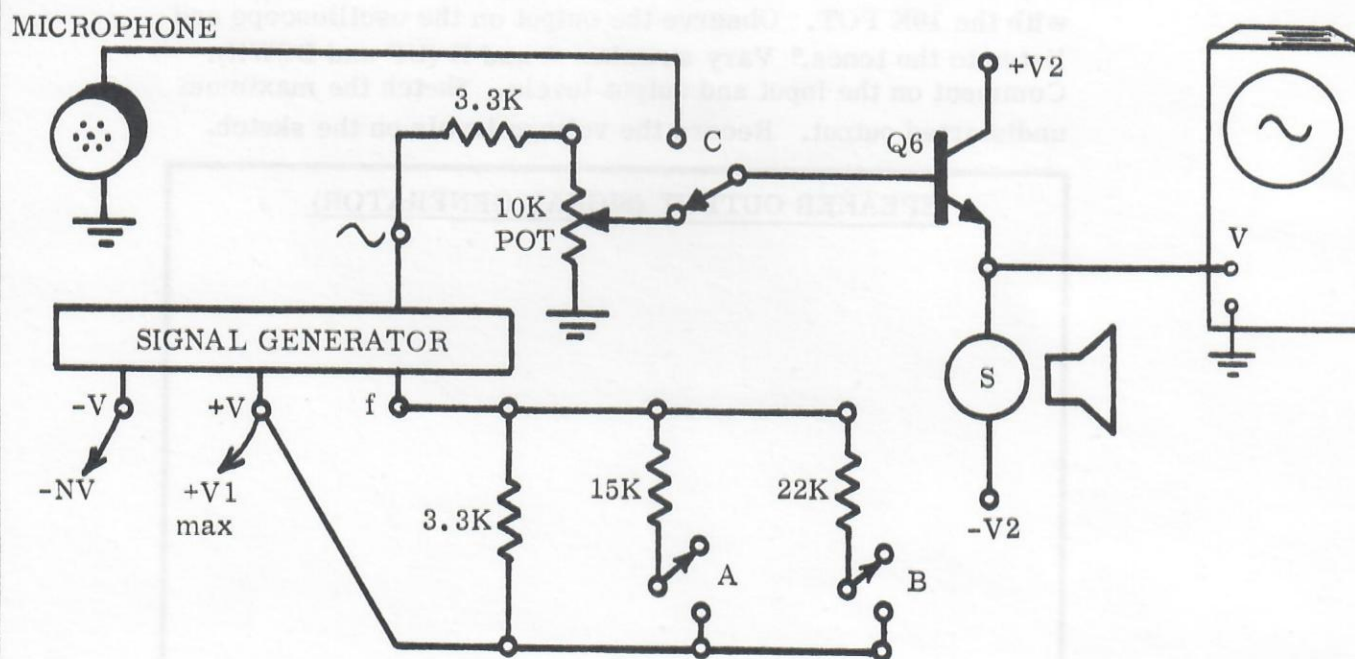


Figure 9-2 Common Collector Amplifier

Objective:

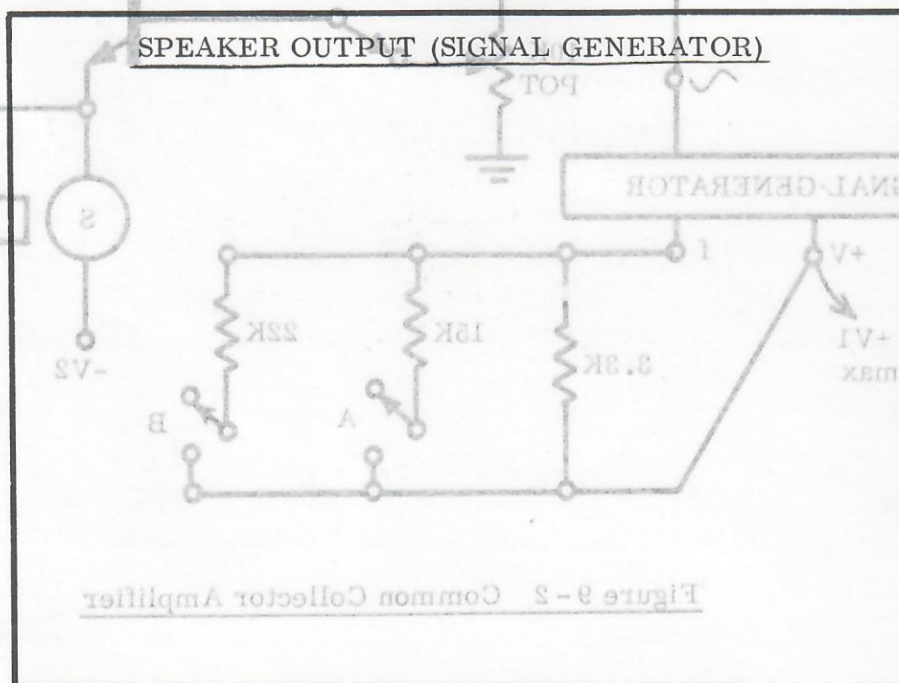
You will use two transistor amplifiers to drive a low resistance loudspeaker. The circuits are a Common-Emitter Amplifier and a Common-Collector Amplifier.

Description:

Loudspeakers generally have resistances of 4 ohms, 8 ohms or 16 ohms. The loudspeaker is the "transducer" which converts the electrical signals to soundwaves in the air as with the earphones. A Transistor Amplifier of the common-emitter type, with the loudspeaker in the collector circuit, is shown in Figure 9-1. A common-collector amplifier or "emitter follower" has the loudspeaker in the emitter circuit as shown in Figure 9-2. The Signal Generator provides an audio tone which is varied by Switches A and B which change the resistance values and the voltage at the "I" input varying the frequency of the tone. Switch C selects the Signal Generator voltage (DOWN) or the microphone voltage (UP) as the input to the amplifier.

Procedure:

1. Wire the circuit in Figure 9-1.
2. Set the input Switch C DOWN.
3. Adjust the 100K POT for proper bias and vary the tone input level with the 10K POT. Observe the output on the oscilloscope and listen to the tones.* Vary switches A and B (UP and DOWN). Comment on the input and output levels. Sketch the maximum undistorted output. Record the voltage levels on the sketch.



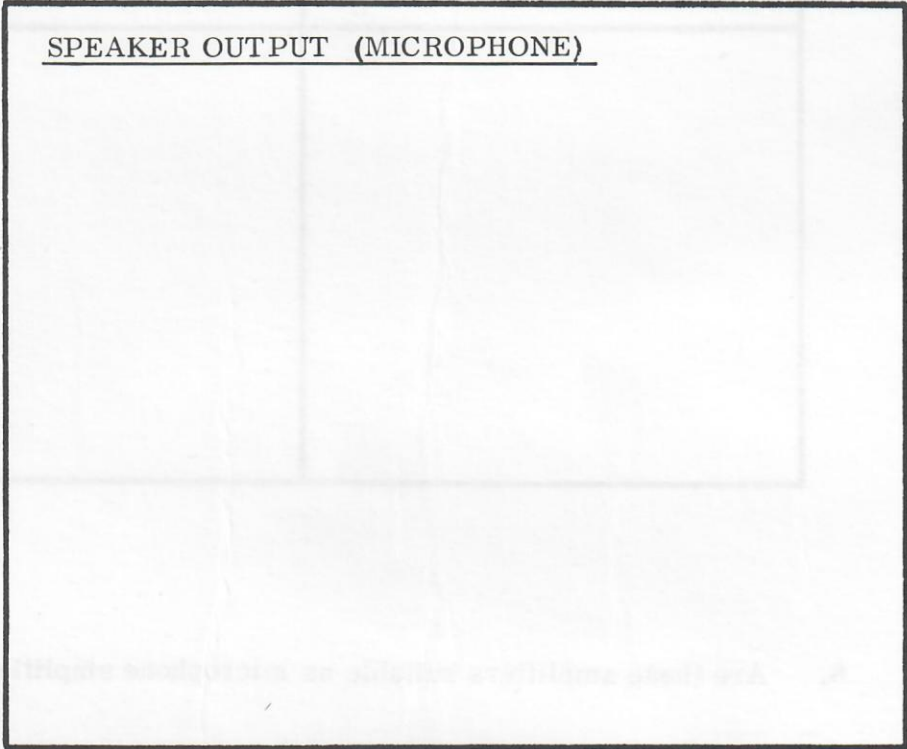
4. Set the input Switch C UP.

* The volume will be low. It may be necessary for one person to speak into the microphone, and another person to listen to the loudspeaker.

Objective:

5. Speak into the microphone. Can you hear any sound from the loudspeaker? Sketch the output waveform resulting from the microphone input when you speak with a normal voice volume. Enter the voltage levels on the sketch.

SPEAKER OUTPUT (MICROPHONE)



6. Disconnect the amplifier from Figure 9 - 1 and substitute the amplifier from Figure 9 - 2.
7. Repeat the output measurements with the Signal Generator input (Switch C DOWN) and with the Microphone input (Switch C UP). Sketch the waveforms and record the voltage levels on the following page.

SPEAKER OUTPUT SIGNALS	
SWITCH C DOWN (Signal Generator)	SWITCH C UP (Microphone)

8. Are these amplifiers suitable as microphone amplifiers?

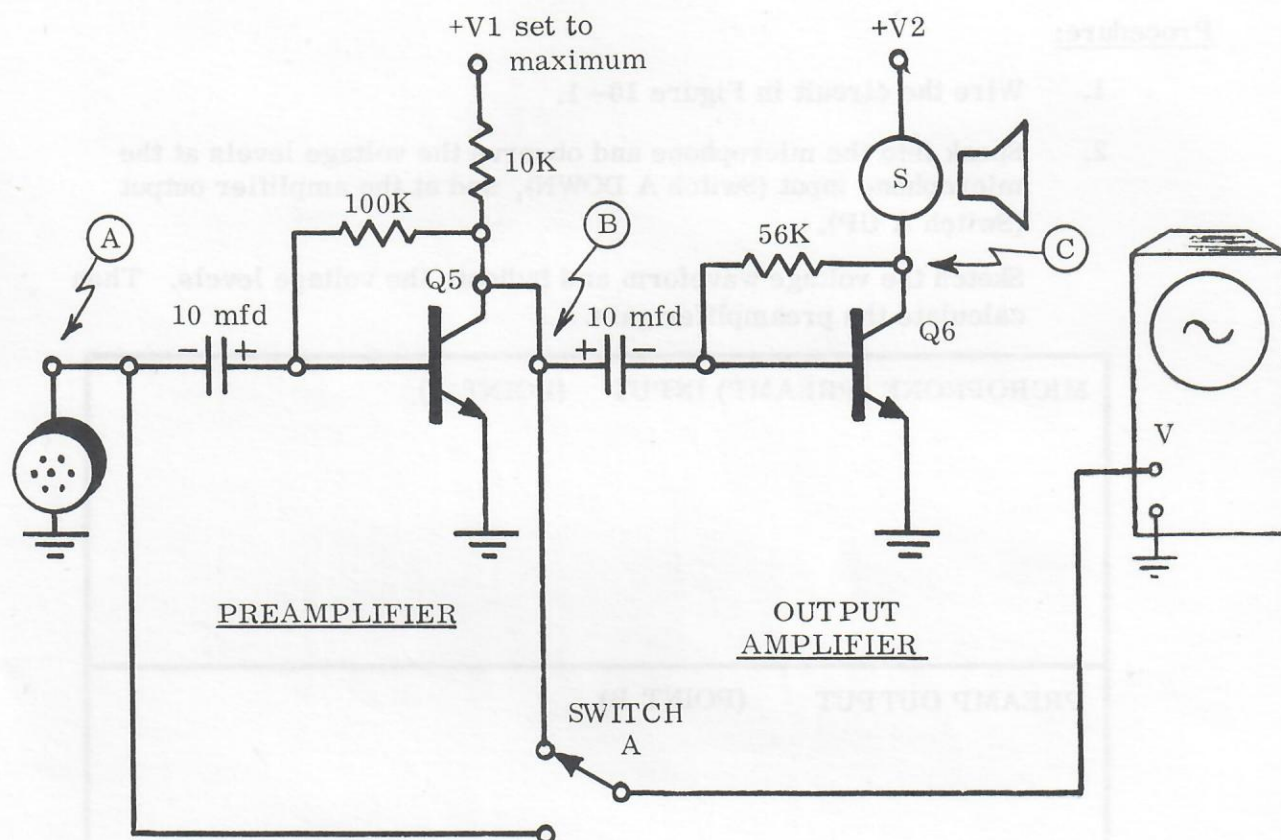


Figure 10 - 1 Audio Preamplifier

Objective:

You will use a Common-Emitter Voltage Amplifier to increase the voltage from the microphone to a level where it is sufficient to drive the output amplifier.

Description:

In the previous experiment, the voltage output from the microphone was not adequate to drive the output audio amplifier. Low level voltage signals are obtained from microphones, radio tuners, phonographs, and tape recorders. It is necessary to provide a high gain preamplifier to increase the voltage level. A simple common emitter amplifier is generally used. The circuit in Figure 10 - 1 uses a collector feedback bias. Other common circuits use a high base-resistor (1 Megohm) to the positive voltage for bias, or an emitter resistor for bias stability as described in experiments in the Transistor Study Unit.

Procedure:

1. Wire the circuit in Figure 10 - 1.
2. Speak into the microphone and observe the voltage levels at the microphone input (Switch A DOWN), and at the amplifier output (Switch A UP).

Sketch the voltage waveform and indicate the voltage levels. Then calculate the preamplifier gain.

MICROPHONE (PREAMP) INPUT (POINT A)

PREAMP OUTPUT (POINT B)

SPEAKER OUTPUT (POINT C)

$$\text{PREAMP VOLTAGE GAIN} = \frac{\text{output voltage (B)}}{\text{input voltage (A)}} =$$

PRE-AMP GAIN =

3. Listen to the speaker output. Compare the audio output level with this preamp circuit to the level without the preamp as used in the previous experiment.
4. Calculate the Input Power. The Microphone has an internal resistance of 2K ohms. The Input Power (at A) is:

$$\text{INPUT POWER} = \frac{V^2}{R} = \frac{(\text{input voltages (A)})^2}{(2,000) (2.8)^2} =$$

The oscilloscope can be used to measure the peak-to-peak voltage. The effective power voltage or RMS voltage is the peak-to-peak voltage divided by 2.8 for a sine-wave.

INPUT POWER =

5. Calculate the Loudspeaker Power. The Loudspeaker has an 8 ohm internal resistance. The Loudspeaker output power (at C) is:

$$\text{LOUDSPEAKER POWER} = \frac{V^2}{R} = \frac{(\text{Loudspeaker Voltage (C)})^2}{8 (2.8)^2}$$

LOUDSPEAKER POWER =

6. Calculate the overall POWER GAIN.

$$\text{POWER GAIN} = \frac{\text{LOUDSPEAKER POWER}}{\text{INPUT POWER}}$$

POWER GAIN =

3. Listen to the speaker output. Compare the audio output level with this previous output to the level without the preamp as used in the previous experiment.
4. Calculate the Input Power. The microphone has an internal resistance of 50 ohms. The input power (P_i) is:

$$\text{INPUT POWER} = \frac{V_i^2}{R_i} = \frac{(\text{input voltage } V_i)^2}{(50 \text{ ohms})}$$

The oscilloscope can be used to measure the peak-to-peak voltage. The effective power voltage or RMS voltage is the peak-to-peak voltage divided by 2.8 for a sine wave.

INPUT POWER =

5. Calculate the Loudspeaker Power. The loudspeaker has an 8 ohm internal resistance. The loudspeaker output power (P_o) is:

$$\text{LOUDSPEAKER POWER} = \frac{V_o^2}{R_o} = \frac{(\text{loudspeaker voltage } V_o)^2}{(8 \text{ ohms})}$$

LOUDSPEAKER POWER =

6. Calculate the overall power gain.

$$\text{POWER GAIN} = \frac{\text{LOUDSPEAKER POWER}}{\text{INPUT POWER}}$$

POWER GAIN =

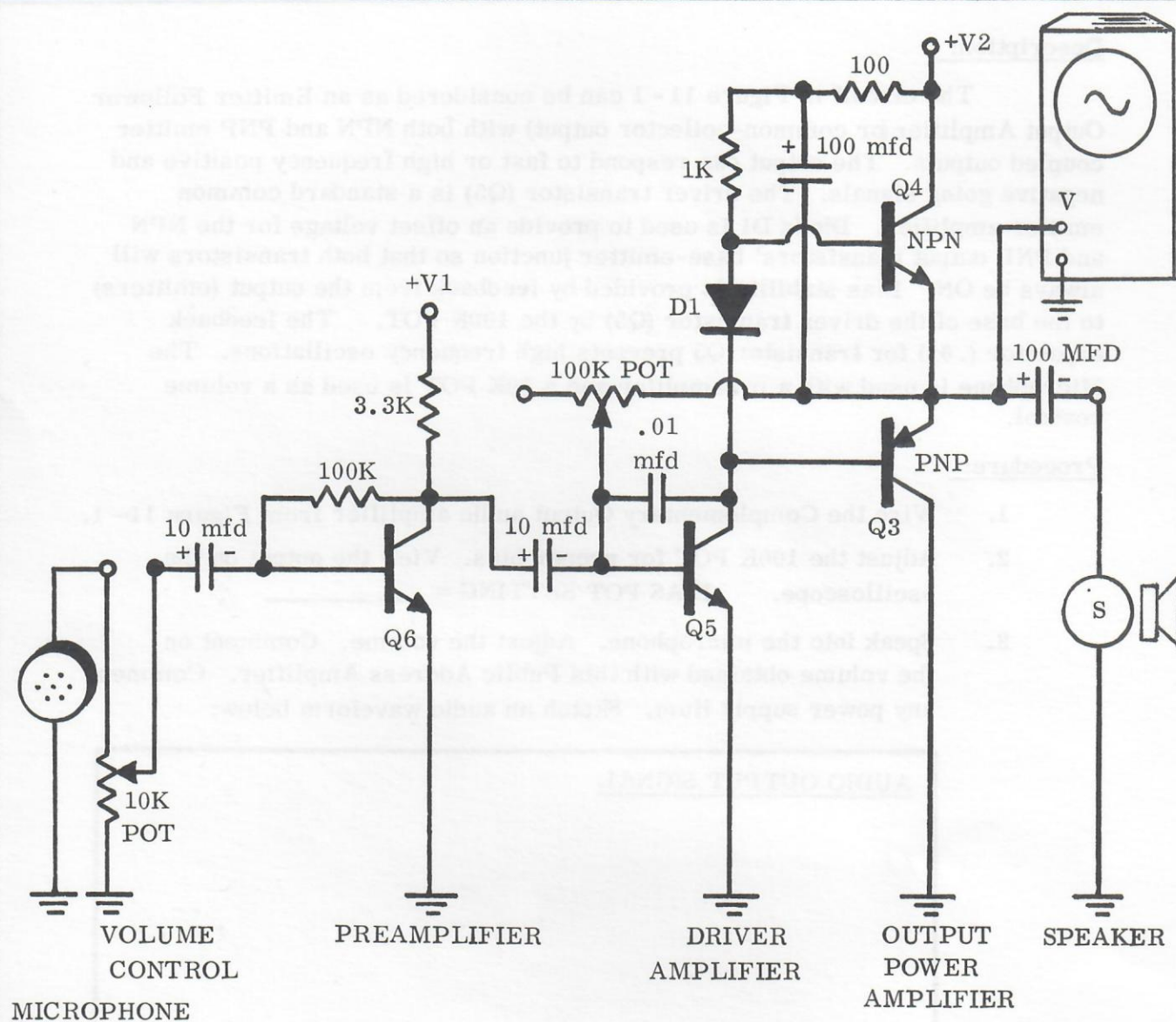


Figure 11-1 Complementary Output Amplifier

Objective:

You will connect an NPN and PNP Transistor in a complementary emitter follower output circuit. A driver amplifier is used and a preamplifier is used in conjunction with the microphone.

Description:

The circuit in Figure 11 - 1 can be considered as an Emitter Follower Output Amplifier (or common-collector output) with both NPN and PNP emitter coupled outputs. The output can respond to fast or high frequency positive and negative going signals. The driver transistor (Q5) is a standard common emitter amplifier. Diode D1 is used to provide an offset voltage for the NPN and PNP output transistors' base-emitter junction so that both transistors will always be ON. Bias stability is provided by feedback from the output (emitters) to the base of the driver transistor (Q5) by the 100K POT. The feedback capacitor (.01) for transistor Q5 prevents high frequency oscillations. The Microphone is used with a preamplifier and a 10K POT is used as a volume control.

Procedure:

1. Wire the Complementary Output audio amplifier from Figure 11 - 1.
2. Adjust the 100K POT for proper bias. View the output on the oscilloscope. BIAS POT SETTING = _____
3. Speak into the microphone. Adjust the volume. Comment on the volume obtained with this Public Address Amplifier. Comment any power supply Hum. Sketch an audio waveform below:

AUDIO OUTPUT SIGNAL

4. Place the microphone near the loudspeaker. Comment on the result.
5. How would you measure the Output Power? How would you measure the Frequency Response?

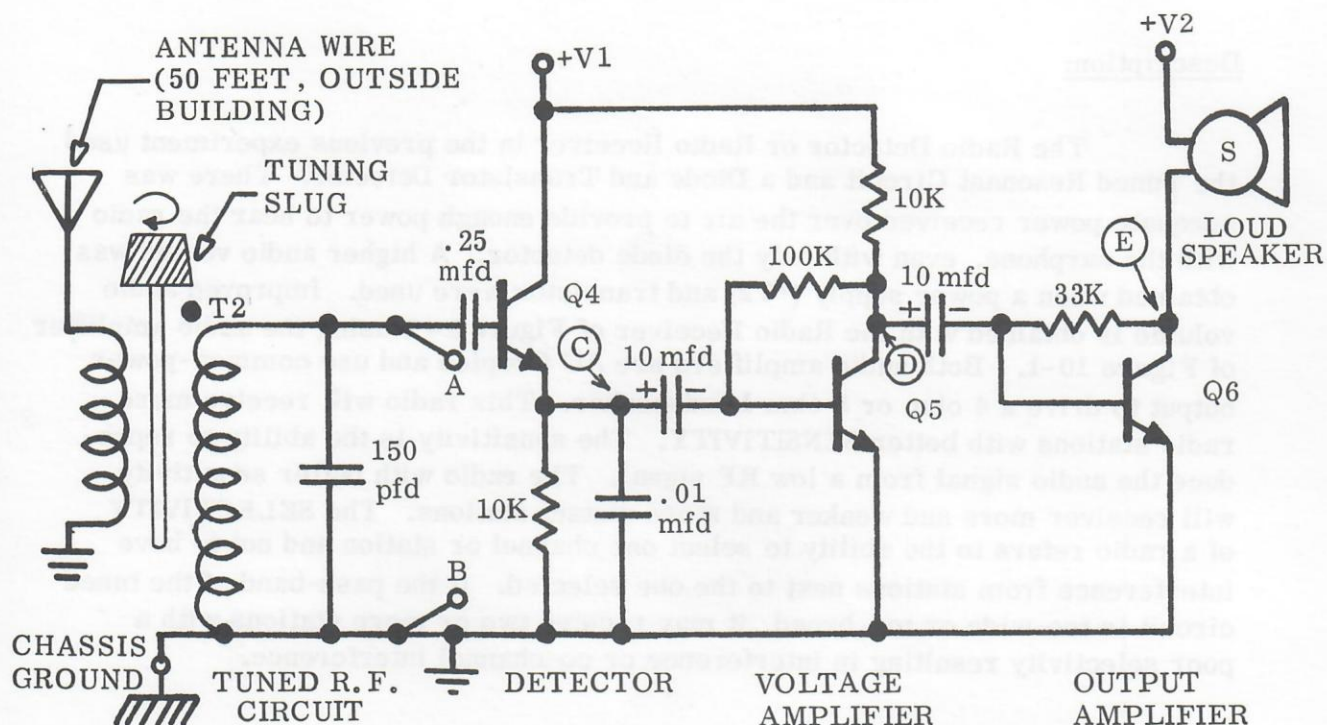


Figure 12- 1 A.M. Radio Receiver

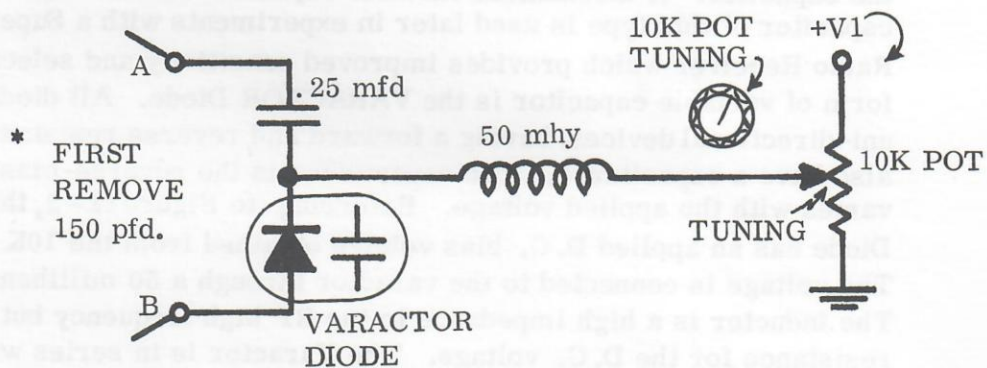


Figure 12-2 Varactor Tuning

Objective:

You will connect two common emitter audio amplifiers to the Transistor Radio Detector to drive a Loudspeaker.

You will replace the tuned circuit with a Varactor (voltage controlled capacitor) to result in a varactor tuned radio.

Description:

The Radio Detector or Radio Receiver in the previous experiment used the Tuned Resonant Circuit and a Diode and Transistor Detector. There was adequate power received over the air to provide enough power to hear the radio with the earphone, even with only the diode detector. A higher audio volume was obtained when a power supply (+V2) and transistor were used. Improved audio volume is obtained with the Radio Receiver of Figure 8-2 using the audio amplifier of Figure 10-1. Both audio amplifiers are AC Coupled and use common-power output to drive a 4 ohm or 8 ohm Loudspeaker. This radio will receive more radio stations with better SENSITIVITY. The sensitivity is the ability to reproduce the audio signal from a low RF signal. The radio with better sensitivity will receive more and weaker and more distant stations. The SELECTIVITY of a radio refers to the ability to select one channel or station and not to have interference from stations next to the one selected. If the pass-band of the tuned circuit is too-wide or too-broad, it may receive two or more stations with a poor selectivity resulting in interference or co-channel interference.

The receiver frequency is determined by the resonant frequency of the tuned circuit. The radio channel frequency is varied by using the RF Coil Tuning slug knob. The frequency can also be varied by changing the value of the capacitor. A mechanical variable capacitor can be used for tuning. A capacitor of this type is used later in experiments with a Superhetrodyne Radio Receiver which provides improved sensitivity and selectivity. Another form of variable capacitor is the VARACTOR Diode. All diodes are not only uni-directional devices, having a forward and reverse resistance, but they also have a capacitance. The capacitance in the reverse-bias direction varies with the applied voltage. Referring to Figure 12-2, the Varactor Diode has an applied D.C. bias voltage obtained from the 10K Potentiometer. The voltage is connected to the varactor through a 50 millihenry inductor. The inductor is a high impedance to the RF high frequency but acts as a low resistance for the D.C. voltage. The Varactor is in series with a 0.25 mfd capacitor to "block" the D.C. Voltage from the tank circuit. The effective capacitance is the series combination of 0.25 mfd and the varactor capacitance which is approximately 150 pfd. Thus, the smaller varactor capacitance is the resultant and varying the 10K POT changes the resonant frequency and the tuning for the radio station.

Procedure:

1. Wire the circuit in Figure 12-1. Keep leads as short as possible. Connect the antenna outside of the building and with about 50 feet of antenna wire. Connect the trainer ground to the Chassis Ground which is connected to the main power Ground with the 3 prong power plug.
2. Listen to various radio stations and record the Station Call Letters, Transmitting Frequency and program content.

STATION	FREQUENCY	CONTENT

3. How many radio stations were received?
4. How was the selectivity between stations?

5. Was the volume high enough for listening?
6. Remove the 150 pfd capacitance from the circuit. Add the circuit from Figure 12-2 to replace the 150 pfd for tuning. Set the supply +V1 to maximum.
7. Vary the 10K POT and observe the effect on the Tuning. What do you estimate is the tuning range?

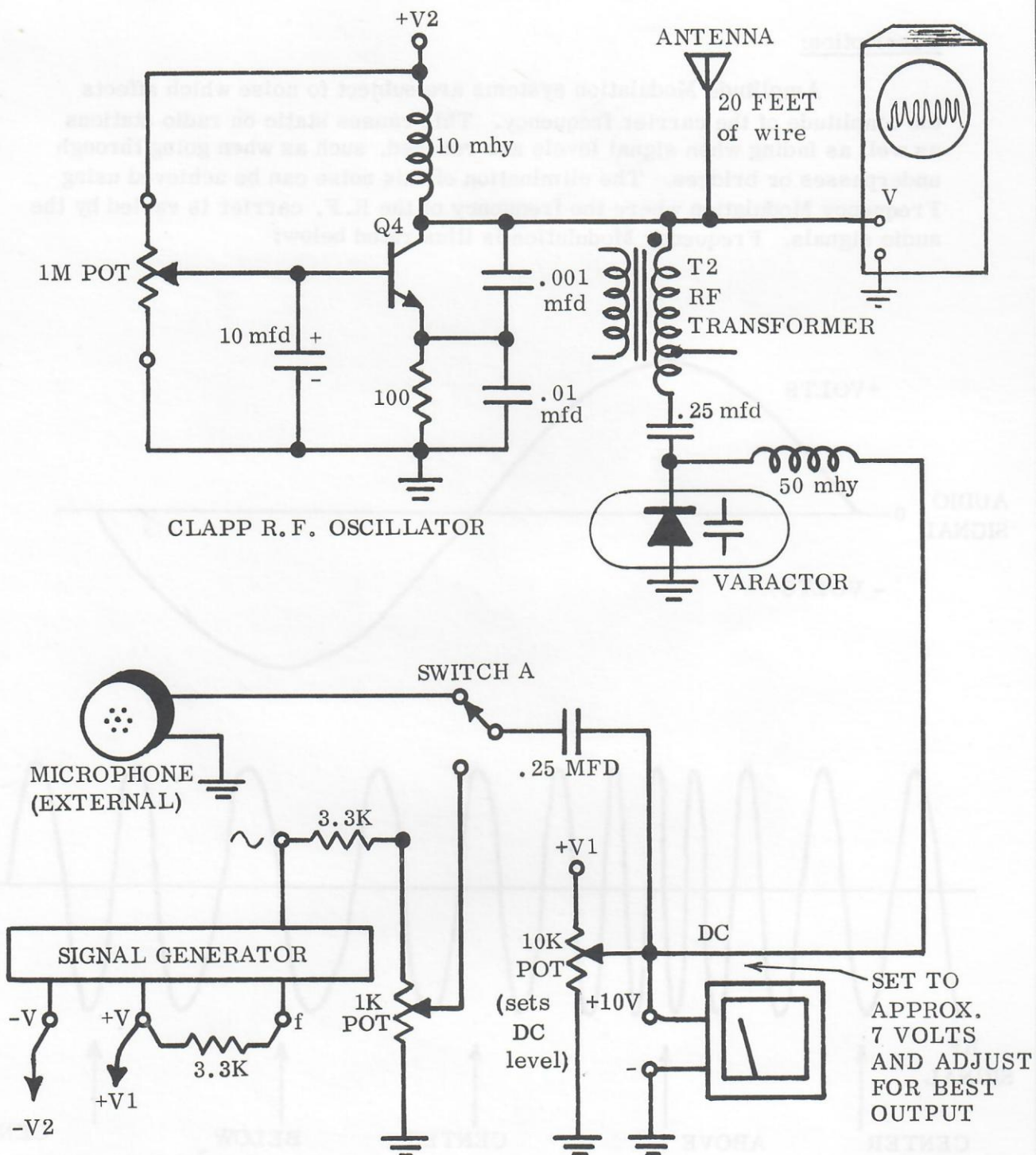


Figure 13-1 Frequency Modulated Oscillator

Objective:

You will review the concept of FREQUENCY MODULATION and use a VARACTOR DIODE to vary the frequency of a Clapp Oscillator resulting in a Frequency Modulated Oscillator.

Description:

Amplitude Modulation systems are subject to noise which affects the amplitude of the carrier frequency. This causes static on radio stations as well as fading when signal levels are reduced, such as when going through underpasses or bridges. The elimination of this noise can be achieved using Frequency Modulation where the frequency of the R.F. carrier is varied by the audio signals. Frequency Modulation is illustrated below:

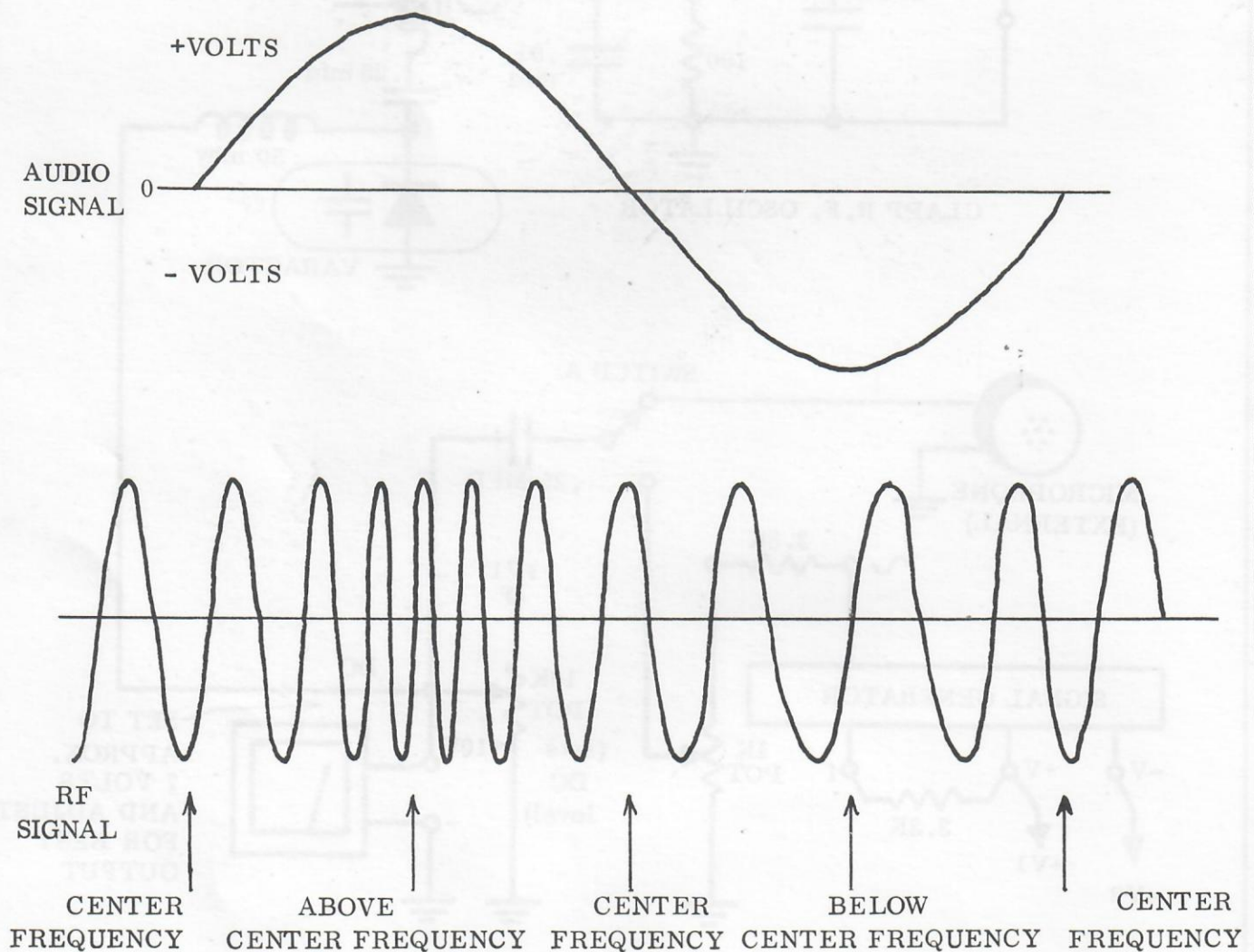


Figure 13-2 F.M. Modulated Carrier

Positive audio voltages result in an increased frequency, and negative audio voltages result in a decreased frequency. The amount of frequency deviation is thus caused by the amplitude or loudness of the audio signal not the frequencies. The "rate" at which the frequency changes is at the frequency of the audio signal. It could thus be possible to shift the frequency by a very large amount for large amplitude signals. The standard FM Radio frequency range is between 88 Megahertz to 100 Megahertz with a maximum frequency shift of 75 Kilohertz specified by the Federal Communications Commission (FCC). There is also a guardband of 25 KHz. The spacing between channels is thus 75 KHz on each side of the carrier (150 KHz) plus the 2 guardbands for a total of 200 KHz wide channels or 200 KHz spacing between FM channels. This results in 100 FM channels. The first channel is at 88.1 MHz and the last channel is at 107.9 MHz.

The amount or percentage of modulation in FM is given by two factors called the deviation ratio and modulation index.

$$\text{MODULATION INDEX} = \frac{\text{GREATEST ALLOWANCE FREQUENCY DEVIATION}}{\text{MODULATING AUDIO FREQUENCY}}$$

The Greatest Allowable Frequency Deviation in FM Broadcast is 75 KHz. Thus, if an audio signal or tone is 3 KHz, the modulation index is 75/3 or 25. In standard commercial FM, the audio frequency range is from 50 Hz to 15 KHz. This is referred to as WIDEBAND FM. There are complex relationships between modulation index, FM sidebands or FM bandwidth, and frequency response or audio fidelity in FM systems. These are not reviewed here. It is noted that the AM bandwidth for a 15 KHz audio would be 30 KHz, while in the FM wideband Radio Broadcast, the bandwidth used is 200 KHz.

$$\text{DEVIATION RATIO} = \frac{\text{GREATEST ALLOWABLE FREQUENCY DEVIATION}}{\text{HIGHEST AUDIO MODULATING FREQUENCY}}$$

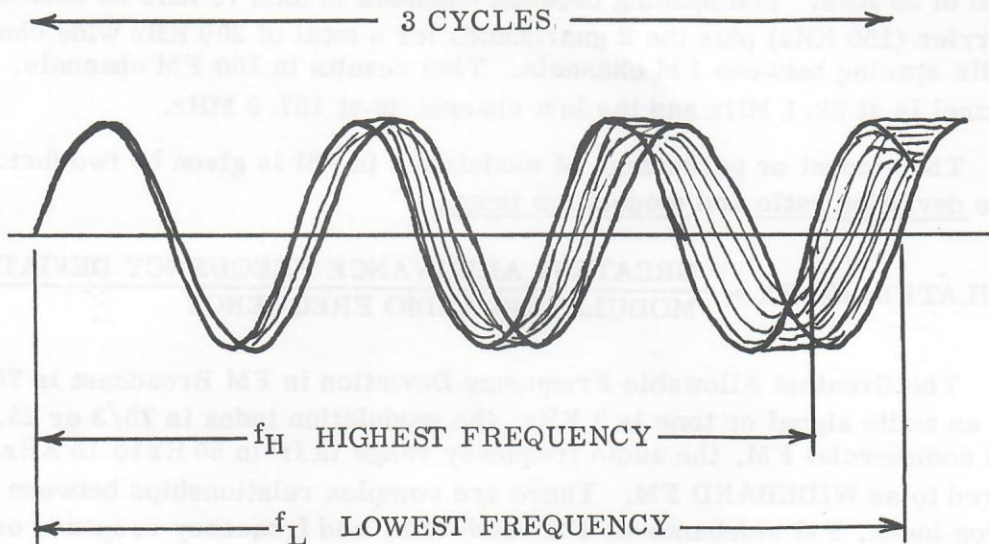
For Standard FM Broadcast, the Highest Audio Frequency is 15 KHz and the Deviation Ratio is always $75/15 = 5$.

The FM Modulator in Figure 13 - 1 uses the CLAPP Oscillator. The frequency is determined by the series inductance (RF transformer T2) and the series capacitance (0.25 mfd in series with the Varactor Diode). As in the Varactor Tuned Radio, the smaller of the two series capacitors (the varactor capacitance at approximately 150 pfd) is the result. The DC voltage set by the 100K POT is applied to the capacitor via the 50 mhy inductor which blocks the RF signal. With Switch A DOWN, the Signal Generator tone is used to modulate the carrier. With Switch A UP, the external microphone is used to modulate the oscillator.

Procedure:

1. Wire the FM Modulated Oscillator circuit in Figure 13 - 1. Set Switch A UP.

2. Adjust the oscilloscope to view the carrier frequency. Set the 1M POT Bias at the Lowest Voltage Level for oscillation. The 10K POT voltage sets the carrier frequency or varactor bias. This should be set for approximately 7 volts. With FM modulation, the scope signal is synchronized at the start of the trace and is sharp, but because of the varying frequency, the sine waves are blurred or spread at the end of the trace. This can be used to measure the frequency variation as shown below:



The time measured for 3 cycles in the drawing can show the high and low frequency deviations. Vary the 1K POT for audio amplitude and observe the frequency variations. Enter measurements and calculate the high and low frequencies.

OSCILLOSCOPE MEASUREMENTS	
CYCLES MEASURED	
High Frequency (TIME)	
Low Frequency (TIME)	

CALCULATIONS

$$f_{\text{HIGH}} =$$

$$f_{\text{LOW}} =$$

$$f_{\text{CARRIER}} =$$

3. Readjust the oscilloscope and measure the Audio Frequency from the Signal Generator.

$$f_{\text{AUDIO}} =$$

4. Calculate the DEVIATION IN FREQUENCY:

$$\text{FREQUENCY DEVIATION} = (f_{\text{HIGH}} - f_{\text{CARRIER}})$$

$$\text{FREQUENCY DEVIATION} =$$

Calculate the MODULATION INDEX based on a 75 KHz Maximum Deviation. Note that the Frequency deviation above only depended on the audio amplitude. The Modulation Index depends on the audio frequency.

$$\text{MODULATION INDEX} = \frac{75 \text{ KHz}}{f_{\text{AUDIO}}}$$

$$\text{MODULATION INDEX} =$$

5. Set Switch A UP. Speak into the microphone and observe the frequency variation on the oscilloscope.

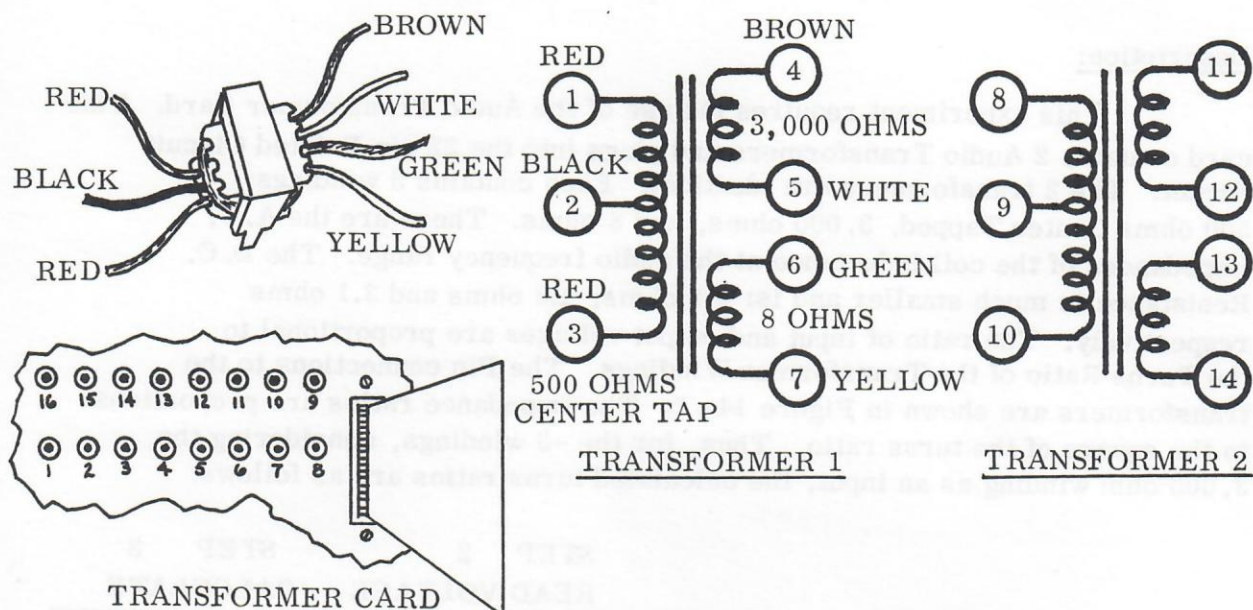


Figure 14 - 1 Audio Transformer Card

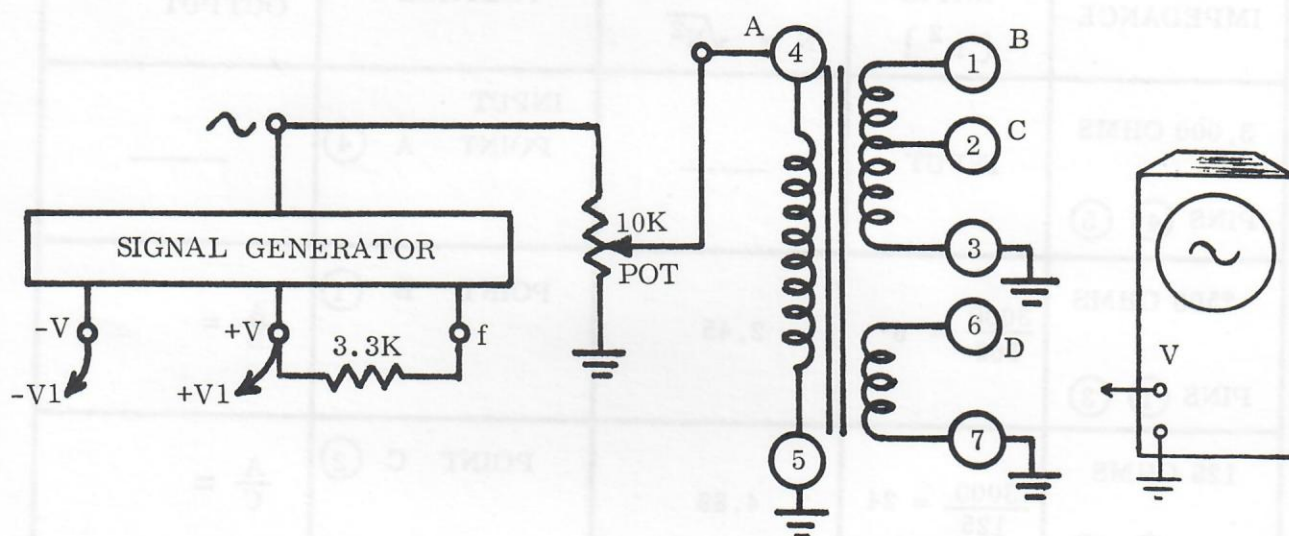


Figure 14 - 2 Transformer Experiment

Objective:

You will test the Audio Transformer card for Voltage ratios between the three separate windings.

Description:

This experiment requires the use of the Audio Transformer Card. This card contains 2 Audio Transformers and plugs into the 22 pin Printed Circuit Socket. The 2 transformers are identical. Each contains 3 windings: 500 ohms Center Tapped, 3,000 ohms, and 8 ohms. These are the A.C. Impedances of the coil inductance at the audio frequency range. The D.C. Resistance is much smaller and is: 0.2 ohms, 1.8 ohms and 3.1 ohms respectively. The ratio of input and output voltages are proportional to the Turns Ratio of the Transformer Windings. The Pin connections to the transformers are shown in Figure 14-1. The impedance ratios are proportional to the square of the turns ratio. Thus, for the -3 windings, considering the 3,000 ohm winding as an input, the calculated turns ratios are as follows:

STEP 2

READ VOLTAGE

STEP 3

CALCULATE

WINDING IMPEDANCE	IMPEDANCE RATIO (N^2)	TURNS RATIO $N = \sqrt{N^2}$	VOLTAGE	$\frac{\text{INPUT}}{\text{OUTPUT}} = N$
3,000 OHMS PINS (4) (5)	INPUT	_____	INPUT POINT A (4)	_____
*500 OHMS PINS (1) (3)	$\frac{3000}{500} = 6^2$	2.45	POINT B (1)	$\frac{A}{B} =$
125 OHMS PINS (2) (3)	$\frac{3000}{125} = 24$	4.89	POINT C (2)	$\frac{A}{C} =$
8 OHMS PINS (6) (7)	$\frac{3000}{8} = 375$	19.36	POINT D (6)	$\frac{A}{D} =$

*NOTE: Because of N^2 impedance ratio, the full winding impedance is actually four times the half winding impedance.

Procedure:

1. Wire the circuit shown in Figure 14-2.

2. Use the oscilloscope to measure the input and outputs. Enter the voltage amplitude (peak-to-peak) in the above table.
3. Calculate the voltage ratios (input to output) and enter the results in the table.
4. How do the ratios compare with the turns ratios (N)?
5. The transformer is used to MATCH the output impedance of the Signal Generator (approximately 1,000 ohms) to the impedance of the Loudspeaker (8 ohms). The transformer is also used for AC COUPLING between an output and a load.

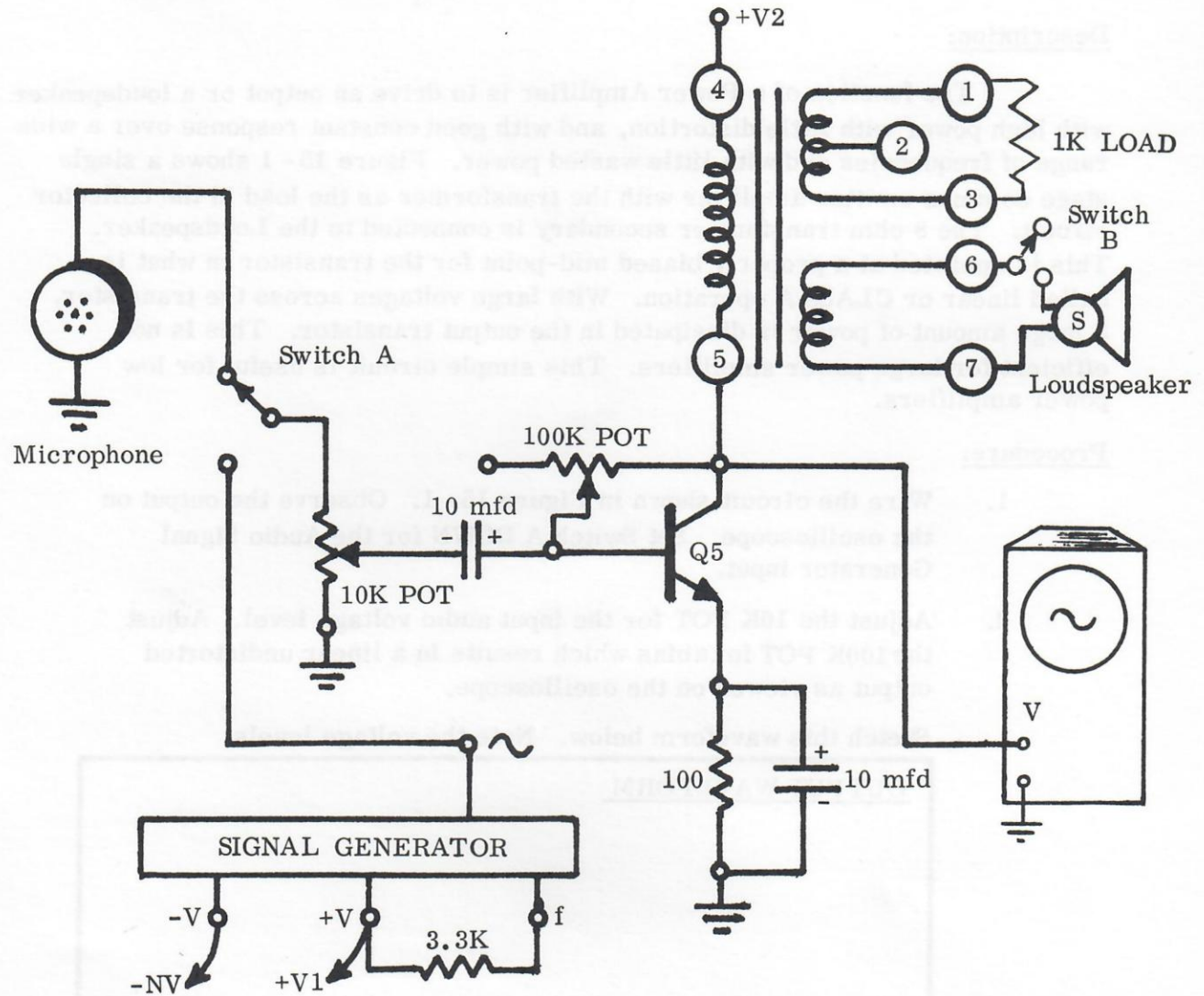


Figure 15 - 1 Single-Ended Transformer Amplifier

Objective:

You will use a T Transformer in a "Single-Ended" Audio Amplifier with transformer coupling from the Output to the Loudspeaker.

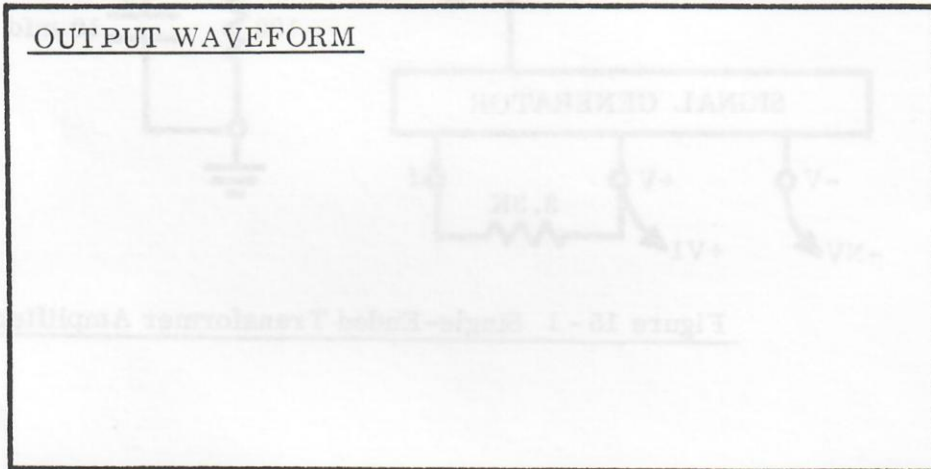
Description:

The function of a Power Amplifier is to drive an output or a loudspeaker with high power with little distortion, and with good constant response over a wide range of frequencies and with little wasted power. Figure 15-1 shows a single stage common emitter amplifier with the transformer as the load in the collector circuit. The 8 ohm transformer secondary is connected to the Loudspeaker. This is operated at a properly biased mid-point for the transistor in what is called linear or CLASS A operation. With large voltages across the transistor, a large amount of power is dissipated in the output transistor. This is not efficient for large power amplifiers. This simple circuit is useful for low power amplifiers.

Procedure:

1. Wire the circuit shown in Figure 15-1. Observe the output on the oscilloscope. Set Switch A DOWN for the Audio Signal Generator input.
2. Adjust the 10K POT for the input audio voltage level. Adjust the 100K POT for a bias which results in a linear undistorted output as viewed on the oscilloscope.

Sketch this waveform below. Note the voltage levels.

OUTPUT WAVEFORM

Estimate the setting of the Bias Potentiometer:

R_f =

3. Set Switch A UP. Speak into the microphone. Observe the output on the oscilloscope.

Description:

In order to reproduce or amplify audio signals without distortion, it was necessary to bias the amplifiers in a linear range of operation to prevent any clipping. This required a bias voltage across the transistor which resulted in power dissipated or lost in the transistor. Linear operation of this type is called CLASS A. For large output power amplifiers, this is not acceptable because of wasted power, but, primarily because this power in the transistor results in large heat dissipation in the transistor. This requires expensive transistors and cooling systems. A better approach is to use a PUSH-PULL system operating in a CLASS B or CLASS AB or CLASS C manner using 2 transistors. The transistors are biased OFF. Output power is only used when an audio signal is present with one transistor furnishing positive signals, and the second transistor furnishing negative signals. The transformer combines the various portions and results in the proper complete output. The Push-Pull Power Output Circuit is driven by a balanced input from a transformer Amplifier Circuit. The oscilloscope is used to monitor the waveforms at various sections of the amplifier:

(A) Audio Input, (B) Driver Amplifier, (C) Single-End of Push-Pull System (not linear), (D) Single - End, (E) Output.

Procedure:

1. Wire the circuit in Figure 16 - 1.
Set the input Switch A DOWN.
2. Monitor the speaker output signal at point E.
3. Adjust the collector bias feedback 100K POT and the 10K volume POT for a maximum undistorted signal at point E.
4. Listen to the output tone. Sketch the waveforms at A, B, C, D, and E below:

Ⓐ AUDIO INPUT

Ⓑ DRIVER AMPLIFIER

*These outputs have the voltages from the current in the half cycle of the push-pull amplifier and also include the "transformer-coupled" voltages from the opposite end of the transformer.

Ⓒ SINGLE-ENDED PUSH-PULL

Ⓓ SINGLE-ENDED PUSH-PULL *

Ⓔ OUTPUT WAVEFORM

5. Connect the Oscilloscope Common to Point G and the VERTICAL INPUT to point F. Record the waveform of the voltage measured across F, G. This waveform is proportional to the base current into Q4. Note that base current and therefore collector current, flows only for 1/2 of the signal cycle indicating class C operation of the transistor.

Ⓕ to Ⓖ WAVEFORM

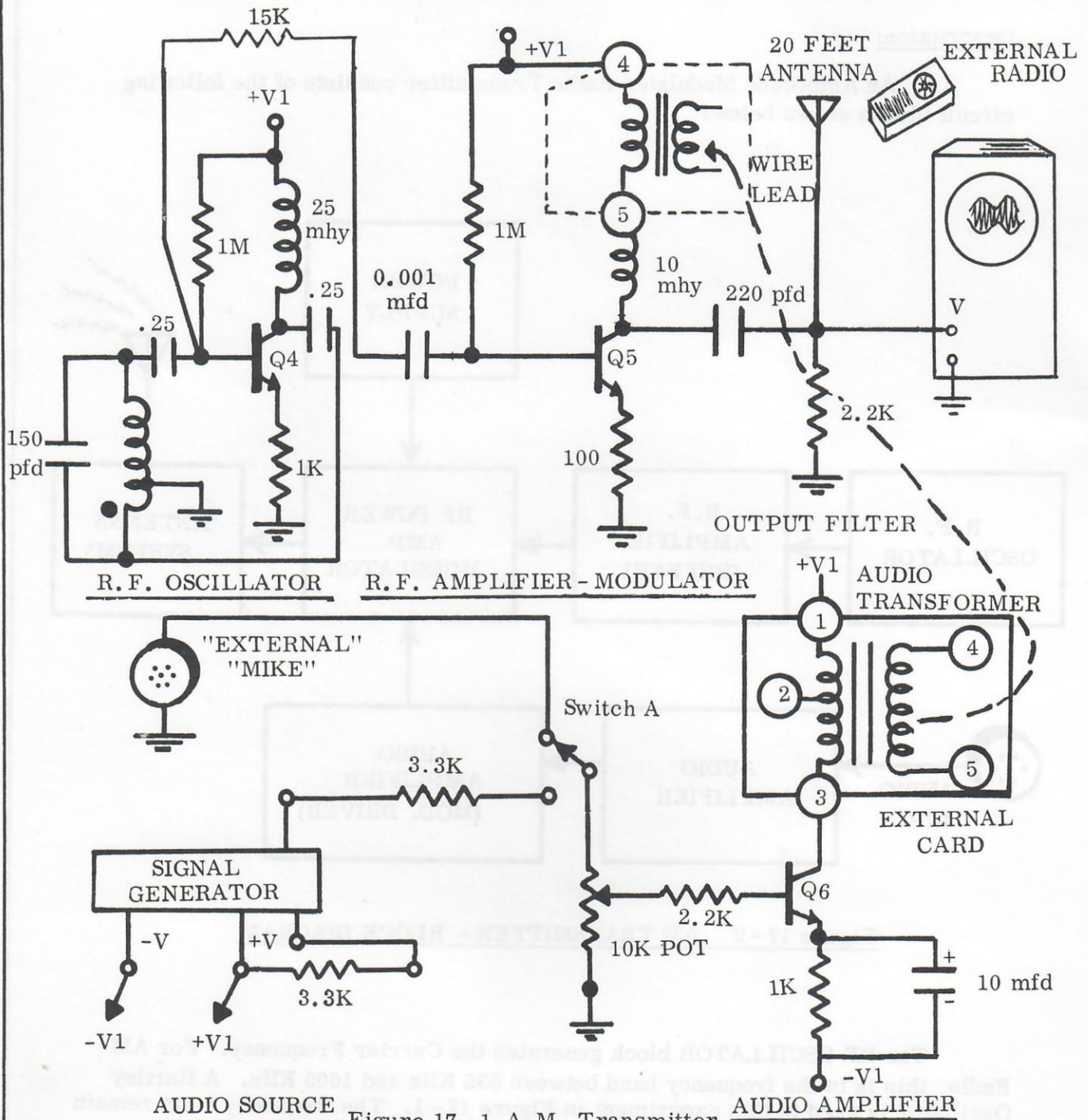


Figure 17 - 1 A.M. Transmitter

Objective:

You will connect an R. F. Oscillator, A. F. Audio Amplifier and an R. F. Amplifier-Modulator as an Amplitude Modulator or A. M. TRANSMITTER. You will then receive the transmitted signal over a standard A. M. Radio. Both the Signal Generator and the "phone" microphone will be used to generate the audio signal.

Description:

An Amplitude Modulated Radio Transmitter consists of the following circuit blocks shown below:

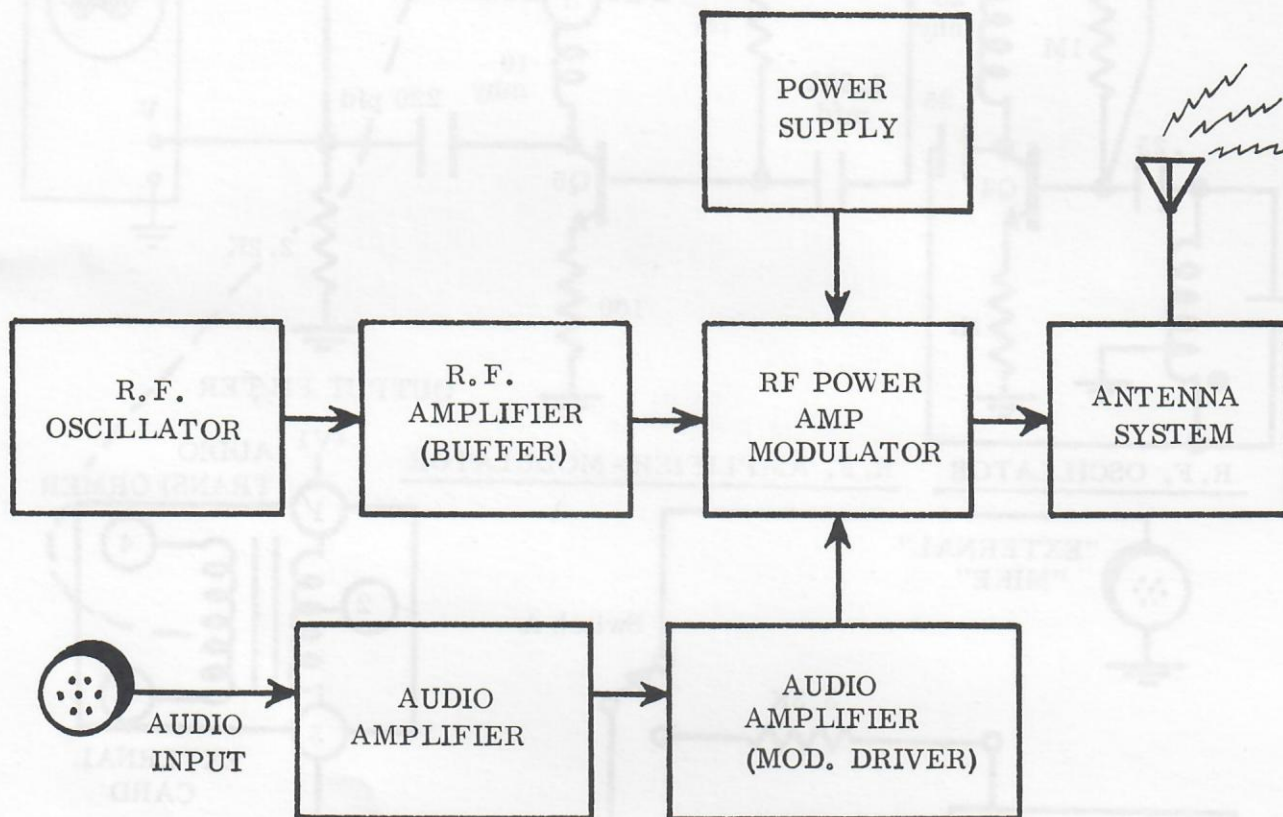


Figure 17 - 2 AM TRANSMITTER - BLOCK DIAGRAM

The RF OSCILLATOR block generates the Carrier Frequency. For AM Radio, this is in the frequency band between 535 KHz and 1605 KHz. A Hartley Oscillator is used in this experiment in Figure 17 - 1. The frequency must remain stable within 20 Hz according to the FCC. To prevent loading which might change the oscillator frequency, and provide higher power for the final Power Amplifier, an intermediate RF AMPLIFIER block is used as a "buffer". Where extremely high carrier frequencies are required, this buffer is "tuned" to higher harmonics of the oscillator frequency to provide 2 or 3 times the oscillator frequency to provide 2 or 3 times the oscillator frequency. Thus an oscillator frequency of

10 MHz may be used and an output carrier frequency of 30 MHz would be generated by the RF BUFFER-MULTIPLIER. A Buffer Amplifier is not used in this experiment.

Modulation can be performed at Low Levels or at a High Level at the Final Power Output Stage. Low Level Modulation is performed in a buffer amplifier and has the advantage of requiring low audio power. However, the RF Power Amplifier must then be linear or class A which has a low power efficiency and much power wasted. High Level Power Modulation is performed directly in the final stage with Class C operation with high power efficiency. The audio amplifier must now provide high power. For a 200 Watt Output Transmitter, 100 Watts of audio modulation is used for 100% modulation in plate modulation. In the Transmitter for this experiment, a High Level Collector Modulation is used at the final RF Power Amplifier and the Modulator Audio Driver is a Single-Ended Transformer Amplifier, with transformer coupling to the output stage. A filter is at the output of the transmitter to make sure that transmission is only at the frequency and band required (not at harmonics), and that the output stage is matched to the antenna. Power Input and Power Output are measured by the Radio Engineer so that he can provide the required output power and so that he can maintain good power efficiency. For a 100% modulated AM signal with 100 watts of carrier RF power, each side band has 25 watts, or 50 watts for the two sidebands.

The antenna performs the function of converting the electrical power to "electromagnetic" energy which is transmitted through the air.

Procedure:

1. Wire the circuit in Figure 17 - 1. Monitor the output on the oscilloscope. Set Switch A DOWN to select the Signal Generator Tone Output.
2. Adjust the input signal amplitude using the 10K POT and observe the output modulated waveform.
3. Use an external radio and tune the radio to receive the proper channel or station where the tone can clearly be heard. If this interferes with a regular station, change the frequency of the oscillator using the inductor tuning knob. Record the station carrier frequency below as read on the radio tuning dial.

$f_{\text{RADIO}} =$

4. Measure the carrier frequency on the oscilloscope.

$$f_{\text{TRANSMITTER}} =$$

How does the measured frequency above compare with the radio dial setting in 3 above?

5. Sketch the output signal below. Enter the voltage levels.

MODULATED SIGNAL OUTPUT

6. Calculate the percentage modulation.

$$\%M = \frac{(E_{\text{max}} - E_{\text{min}})}{(E_{\text{max}} + E_{\text{min}})} \times 100\%$$

$$\% \text{ MODULATION} =$$

7. Set Switch A UP. The microphone now generates the audio signal. Speak into the microphone and listen to the output received over the external radio.

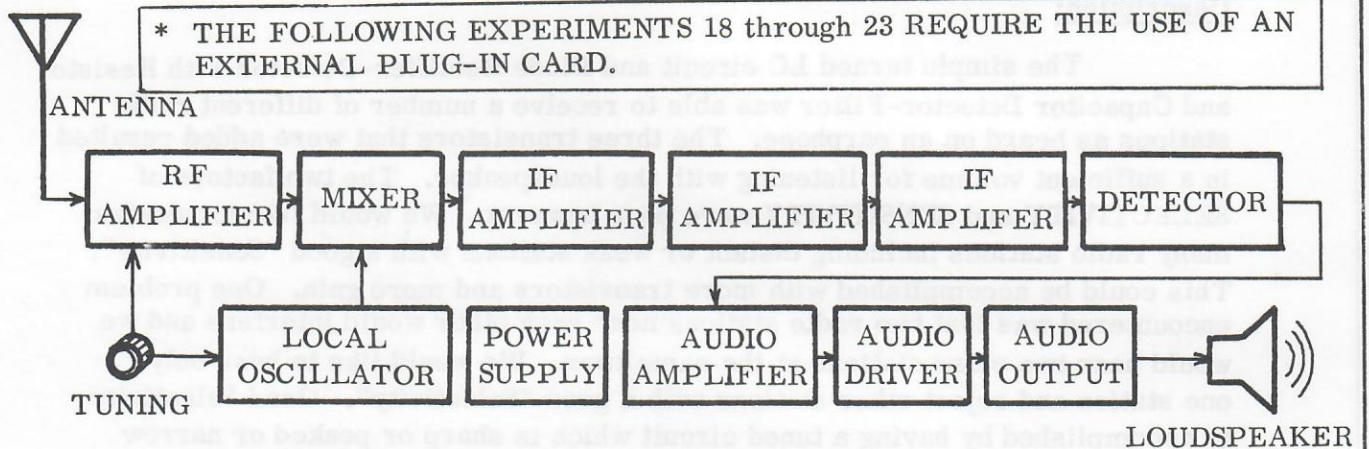


Figure 18 - 1 Superhetrodyne Receiver - BLOCK DIAGRAM

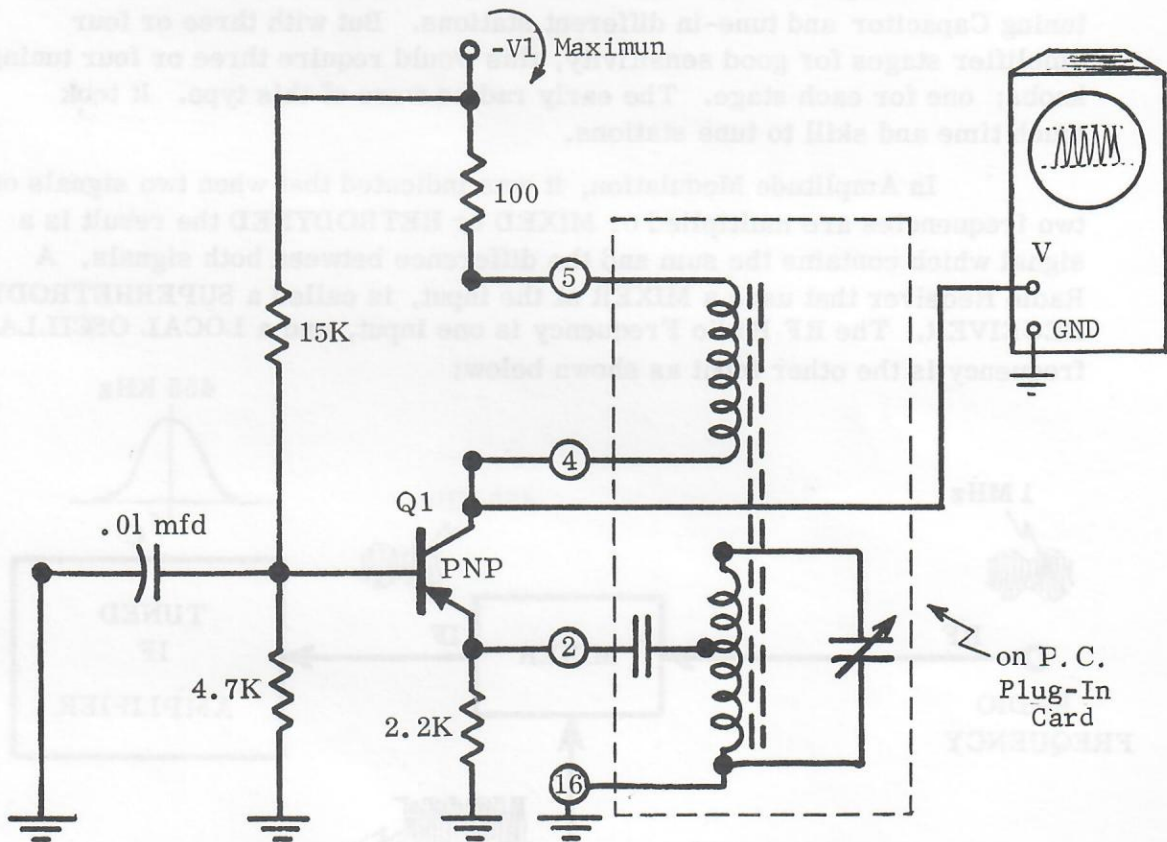


Figure 18 - 2 Local Oscillator

Objective:

You will review the concept of the Superhetrodyne Radio Receiver and build and test the LOCAL OSCILLATOR.

Description:

The simple turned LC circuit and Diode Rectifier-Detector with Resistor and Capacitor Detector-Filter was able to receive a number of different radio stations as heard on an earphone. The three transistors that were added resulted in a sufficient volume for listening with the loudspeaker. The two factors of SELECTIVITY and SENSITIVITY were poor however. We would like to receive many radio stations including distant or weak stations with a good "Sensitivity". This could be accomplished with more transistors and more gain. One problem encountered was that two radio stations near each other would interfere and we would hear two close stations at the same time. We would like to hear only one station and reject other stations with a good "Selectivity". Good Selectivity is accomplished by having a tuned circuit which is sharp or peaked or narrow at the center frequency or carrier frequency. This would be a resonant tuned circuit with a high Q or Quality Factor. Typically, one would then vary the tuning Capacitor and tune-in different stations. But with three or four amplifier stages for good sensitivity, this would require three or four tuning knobs; one for each stage. The early radios were of this type. It took much time and skill to tune stations.

In Amplitude Modulation, it was indicated that when two signals of two frequencies are multiplied or MIXED or HETRODYNE the result is a signal which contains the sum and the difference between both signals. A Radio Receiver that uses a MIXER at the input, is called a SUPERHETRODYNE RECEIVER. The RF Radio Frequency is one input, and a LOCAL OSCILLATOR frequency is the other input as shown below:

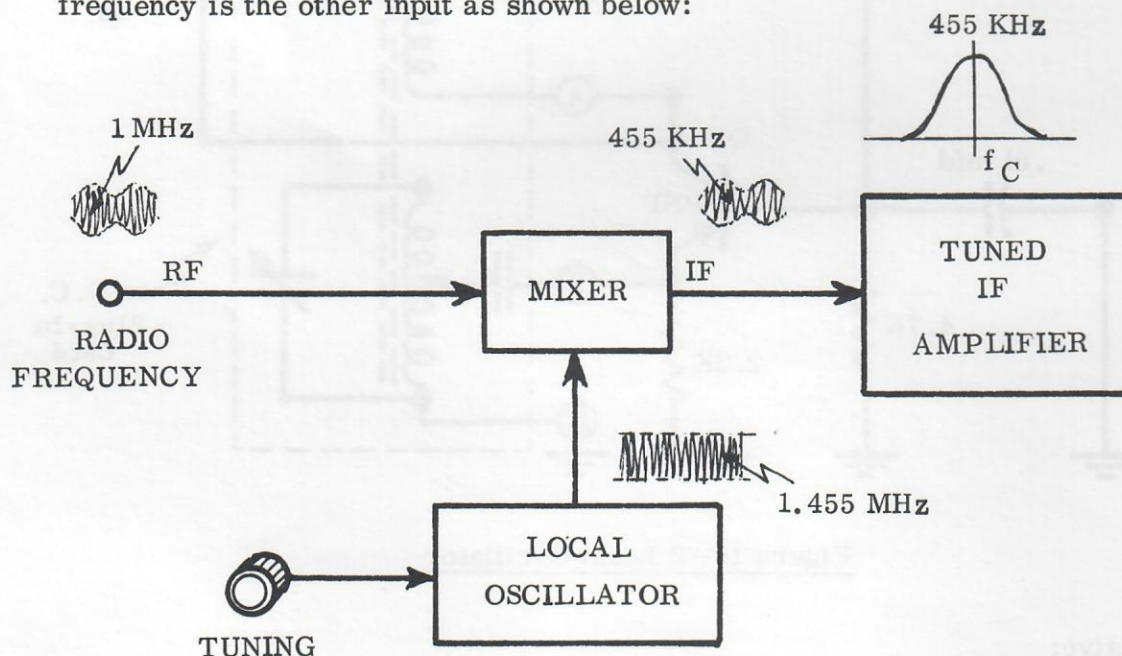


Figure 18 - 3 Input Stage - Superhetrodyne Mixer

Consider that we wish to receive a station with a Radio Frequency of 1 MHz. We tune the Local Oscillator at a frequency of 1.455 MHz. The output of the Mixer is the sum and difference or 2.455 MHz and 455 KHz. We apply this output to a Tuned Amplifier at a frequency of 455 KHz, rejecting the upper band, and amplify this Intermediate Frequency (IF) with a Tuned Amplifier to obtain both good Sensitivity and good Selectivity.

If we desire to tune a nearby station at 1.2 MHz then we only have to increase the tuning of the Local Oscillator by .2MHz to 1.655 MHz. The only frequency that would be amplified by the tuned IF amplifier is 455 KHz which corresponds to an incoming RF frequency of 1.2 MHz. The radio is thus tuned to 1.2MHz and this signal is amplified by the IF Amplifier.

The BLOCK DIAGRAM in Figure 18 - 1 shows the RF AMPLIFIER MIXER and OSCILLATOR, followed by three IF AMPLIFIERS, the DETECTOR, and AUDIO AMPLIFIERS, and a POWER SUPPLY.

The AM Radio Experiments require Tuned Components which are on separate plug-in card containing the following items:

ANTENNA COIL
TUNING CAPACITOR
OSCILLATOR COIL
IF TRANSFORMER 1
IF TRANSFORMER 2
IF TRANSFORMER 3

The six components are connected to the 16 Pins on the P.C. Card Connector with terminal connections as shown on the following page.

The LOCAL OSCILLATOR circuit is shown in Figure 18 - 2. The Oscillator Transformer Coil couples the collector and emitter circuit to result in a variable frequency oscillator. The Coil and Variable Capacitor are both connected to each other on the card. A 0.01 mfd capacitor is connected to the oscillator coil and is located on the card. This capacitor couples the coil to the transistor emitter.

The 0.01 mfd capacitor between the Transistor Base and Ground provides an A.C. Bypass needed for the high gain required for oscillation.

Procedure:

1. Wire the Local Oscillator Circuit in Figure 18 - 2.

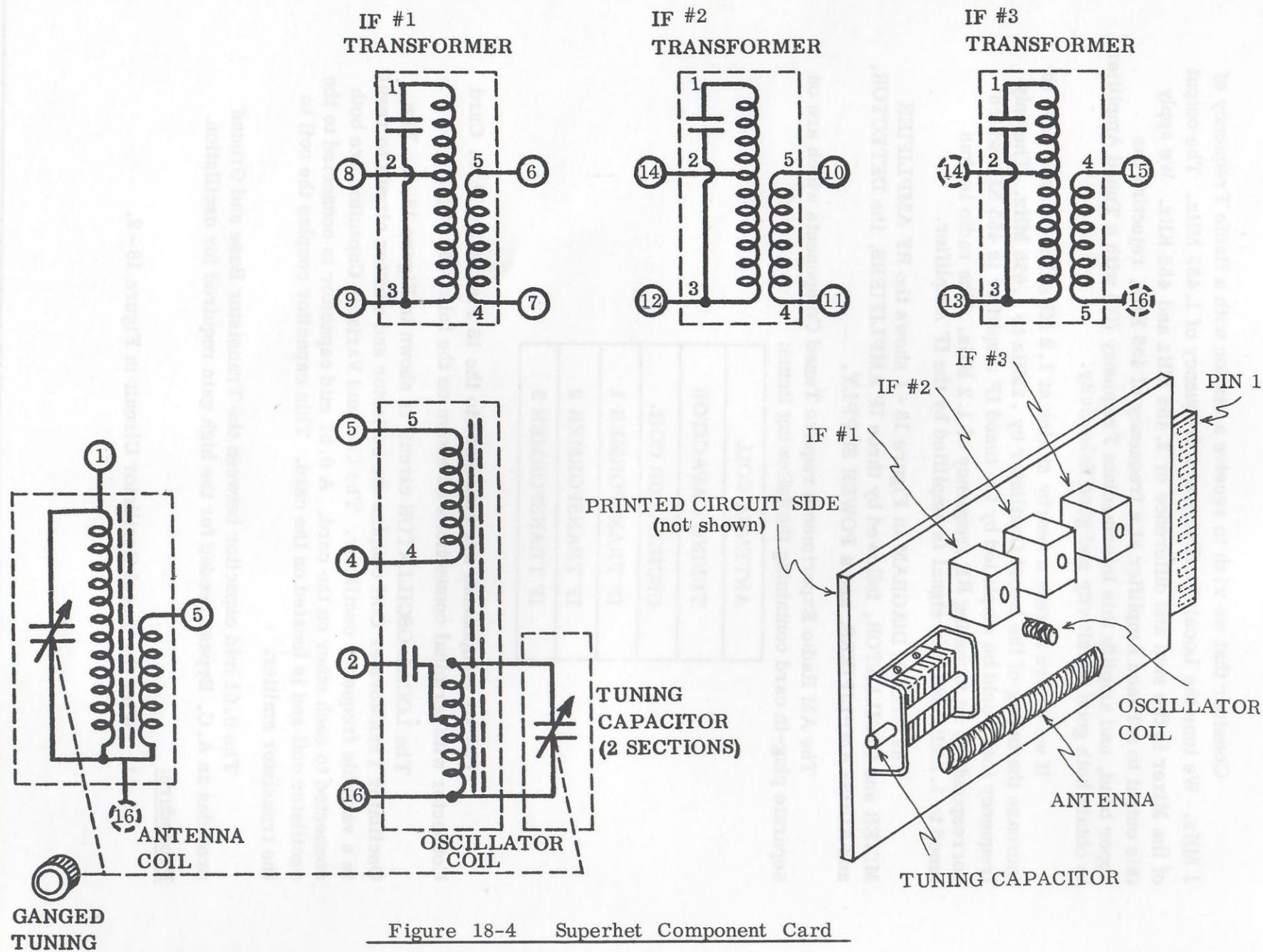


Figure 18-4 Superhet Component Card

2. Observe the output on the oscilloscope. Vary the tuning capacitor on the card and measure and record the frequency range.

f_{LOWEST}	=
f_{HIGHEST}	=

3. The local Oscillator frequency must be 455 KHz higher than the tuning frequency. Subtract 455 KHz and determine the tuning range of this Local Oscillator

R.F. TUNING RANGE

f_{LOW}	=
f_{HIGH}	=

4. Is this R.F. Tuning Range within the AM Radio Band of 540 KHz to 1,600 KHz?

3. Observe the output on the oscilloscope. Vary the tuning capacitor on the coil and measure and record the frequency range.

HIGHEST	=
LOWEST	=

4. The local oscillator frequency must be 455 KHz higher than the radio frequency. Calculate 455 KHz and determine the tuning range of the Spectrum Receiver.

R.F. TUNING RANGE

LOW	=
HIGH	=

5. Is this R.F. Tuning Range within the AM Radio Band of 540 KHz to 1.6 MHz?

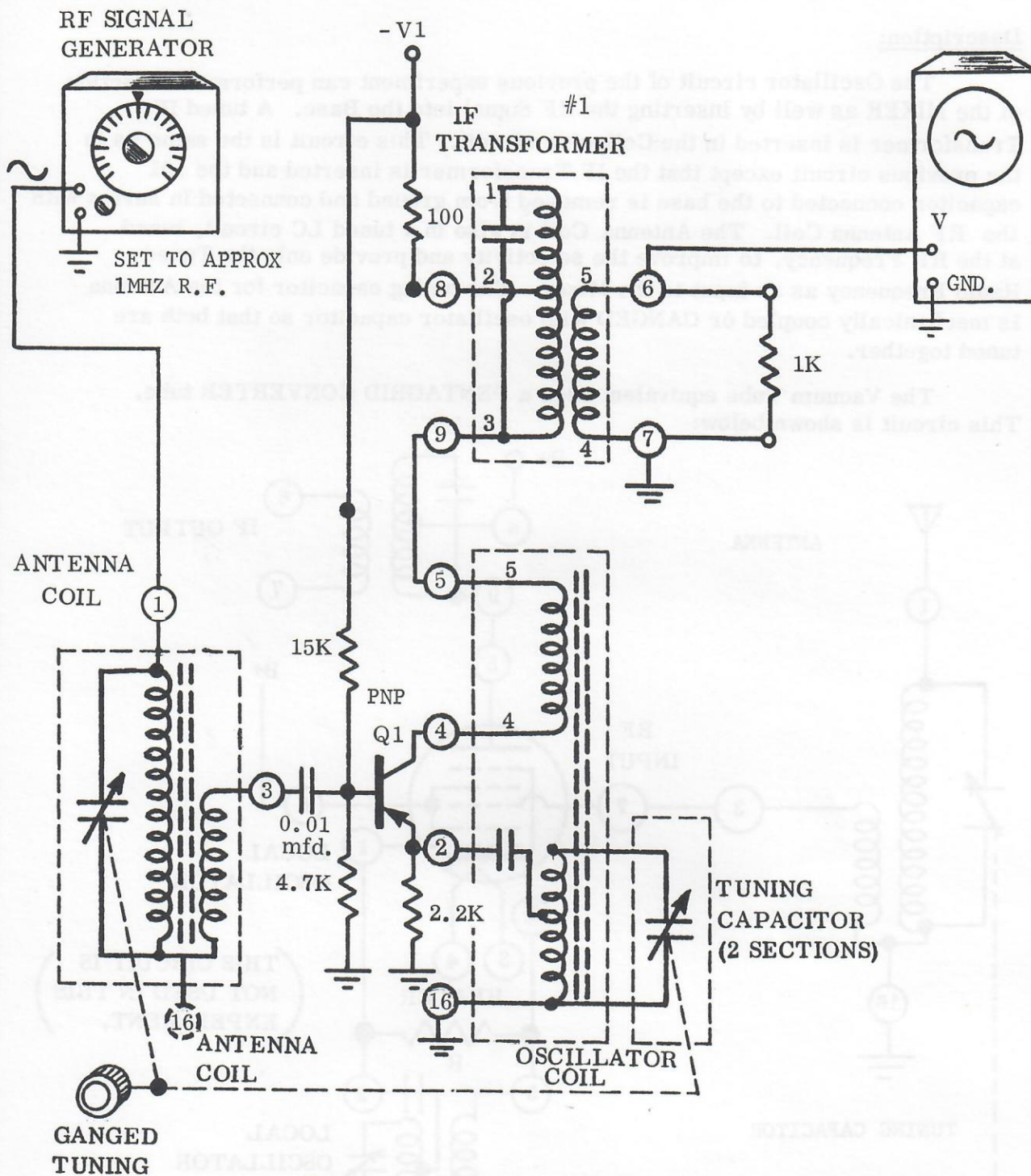


Figure 19-1 Superhetrodyne Converter - Experiment

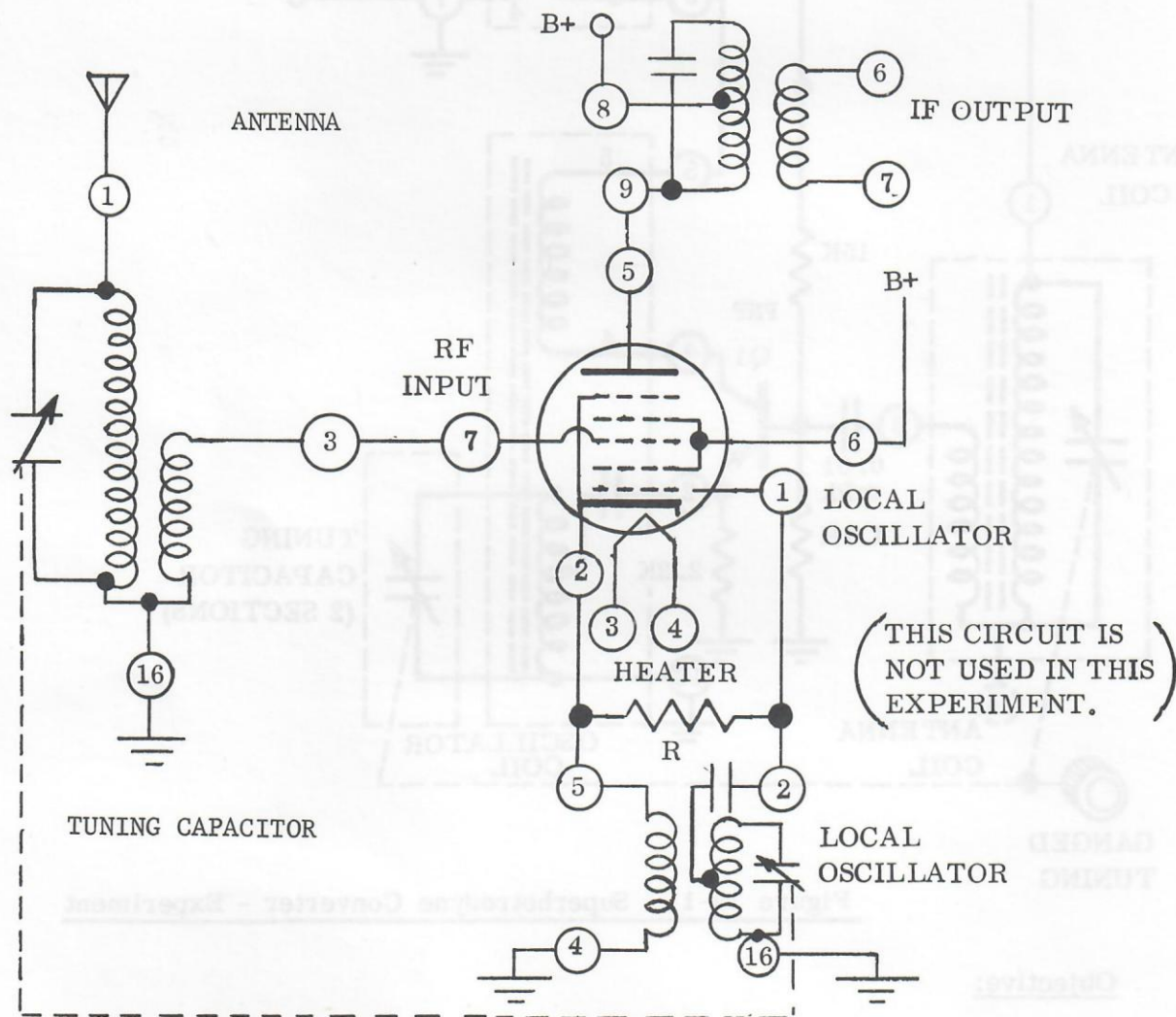
Objective:

You will observe the output of a Superhetrodyne CONVERTER which combines the function of the RF AMPLIFIER MIXER, LOCAL OSCILLATOR and IF TUNED CIRCUIT AMPLIFIER into a single circuit.

Description:

The Oscillator circuit of the previous experiment can perform the function of the MIXER as well by inserting the RF Signal into the Base. A tuned IF Transformer is inserted in the Collector circuit. This circuit is the same as in the previous circuit except that the IF Transformer is inserted and the .01 capacitor connected to the base is removed from ground and connected in series with the RF Antenna Coil. The Antenna Coil is also in a tuned LC circuit, tuned at the RF Frequency, to improve the selectivity and provide only the Tuned Radio Frequency as an input to the Mixer. The tuning capacitor for the Antenna is mechanically coupled or GANGED with oscillator capacitor so that both are tuned together.

The Vacuum Tube equivalent uses a PENTAGRID CONVERTER tube. This circuit is shown below:

Procedure:

1. Wire the CONVERTER circuit in Figure 19-1. The NPN TEST Oscillator has a frequency in the radio band. This is used for testing the Mixer.

2. Observe the output from the IF Transformer. This output will be the mixed combination of the RF Signal Frequency, the Local Oscillator Frequency, and the Mixed (IF) Frequency. When there is no RF Input, there will be a very low signal corresponding to the Local Oscillator frequency. When a High R.F. Signal is present (at the Test Oscillator Frequency), the Mixed IF Frequency Signal will be high.

Vary the Radio Tuning Capacitor on the card. Observe the output waveform when the Receiver Mixer is not tuned to the Test Oscillator.

Sketch the waveforms below: Indicate the voltage levels (peak to peak) and the Frequency.

WAVEFORMS

NOT TUNED TO R.F

(Frequency = *)

TUNED TO R.F

(Frequency =)

3. When the Receiver is not tuned to the RF "station", does the output frequency vary and correspond to the local oscillator?

* Frequency may be difficult to observe because of the level.

4. When the Receiver is tuned, what is the frequency at the IF frequency?
5. What are the output voltage levels when the receiver is out of tune, and when tuned.

VOLTAGE (NOT TUNED)	=
VOLTAGE (TUNED)	=

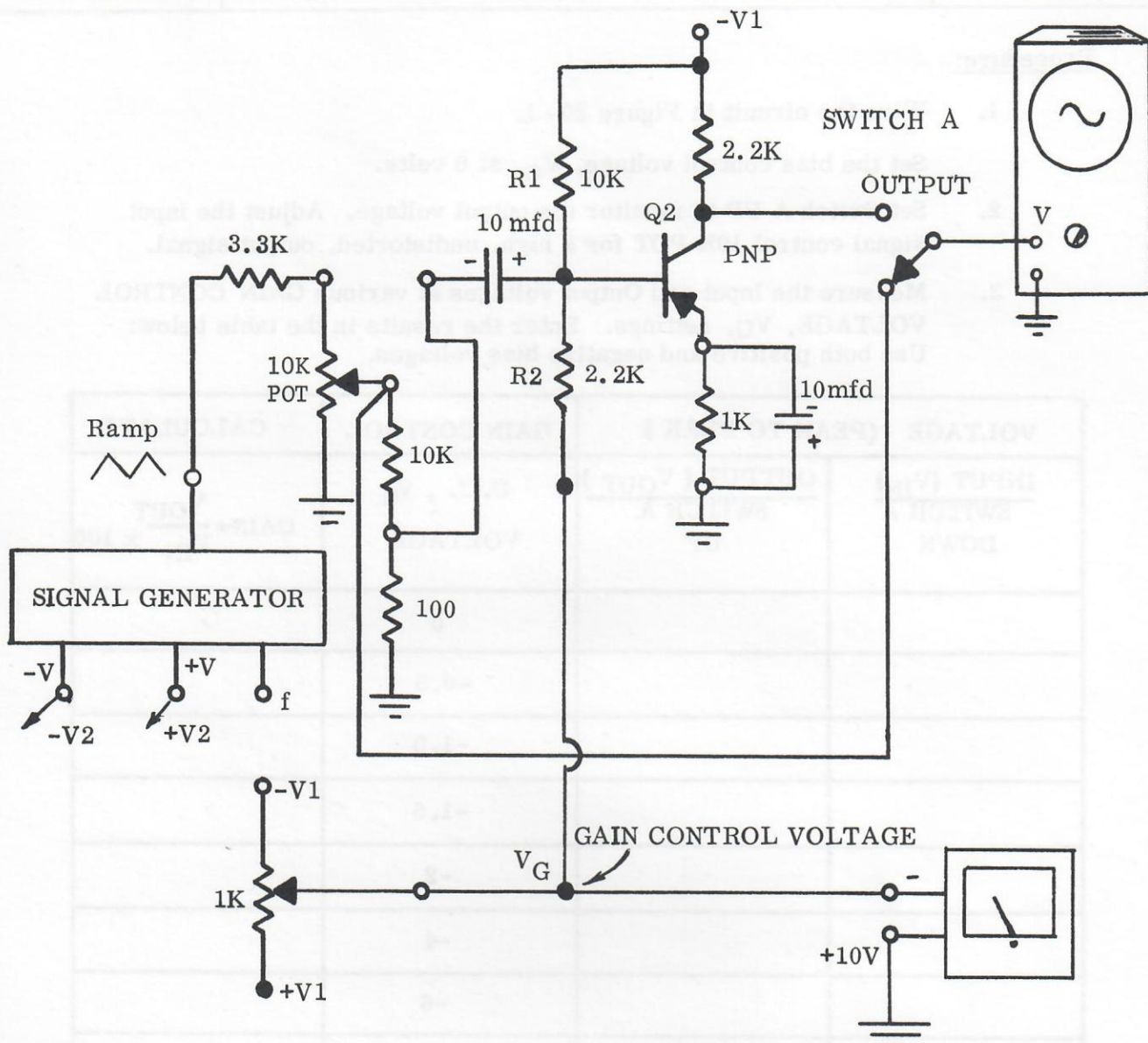


Figure 20 - 1 VARIABLE GAIN AMPLIFIER - EXPERIMENT

Objective:

You will vary the Bias point on a Common Emitter Amplifier and observe the variation in Amplifier Gain.

Description:

The Common Emitter Amplifier has a bias point established by the voltage divider using R1 and R2 and by the supply voltage $-V_1$ and the bias control voltage, V_G . The Signal Generator provides a test input signal through a 10K to 100 ohm attenuator.

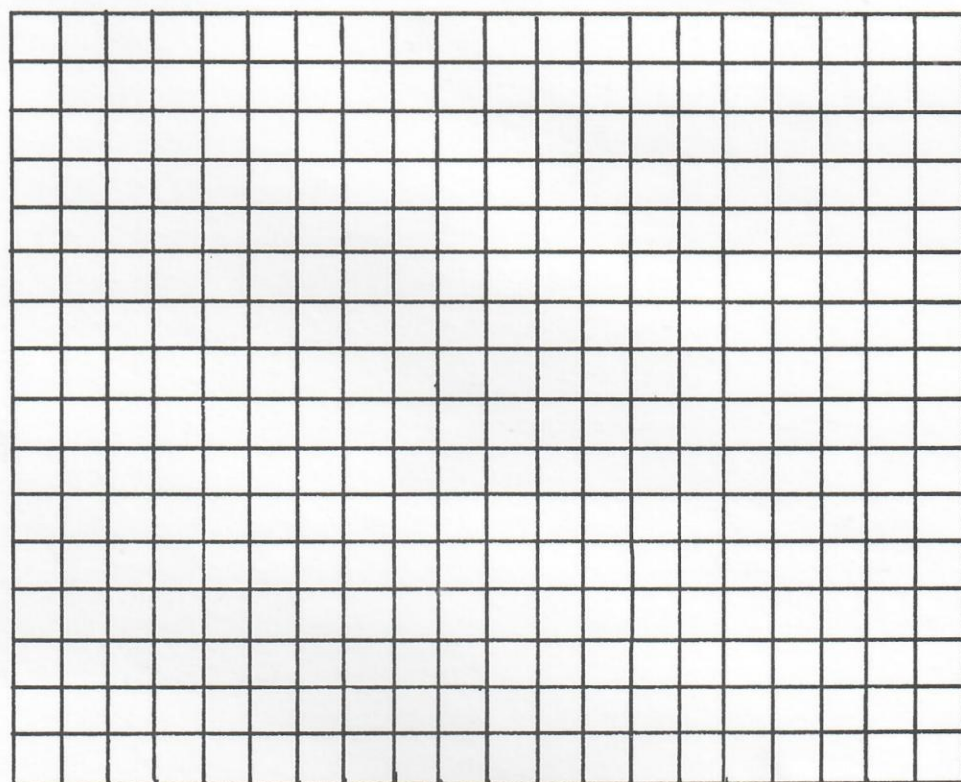
Procedure:

1. Wire the circuit in Figure 20 - 1.
Set the bias control voltage, V_G , at 0 volts.
2. Set Switch A UP to monitor the output voltage. Adjust the input signal control 10K POT for a high, undistorted, output signal.
3. Measure the Input and Output voltages at various GAIN CONTROL VOLTAGE, V_G , settings. Enter the results in the table below:
Use both positive and negative bias voltages.

VOLTAGE (PEAK TO PEAK)		GAIN CONTROL	CALCULATE
INPUT (V_{IN}) SWITCH A DOWN	OUTPUT (V_{OUT}) SWITCH A UP	D.C. , V_G VOLTAGE	$GAIN = \frac{V_{OUT}}{V_{IN}} \times 100$
		0	
		-0.5	
		-1.0	
		-1.5	
		-2	
		-4	
		-6	
		+0.5	
		+1	
		+1.5	
		+2.0	
		+3	
		+4	

4. Calculate the Gain and enter it in the table on preceding page.
5. Plot the results below:

GAIN

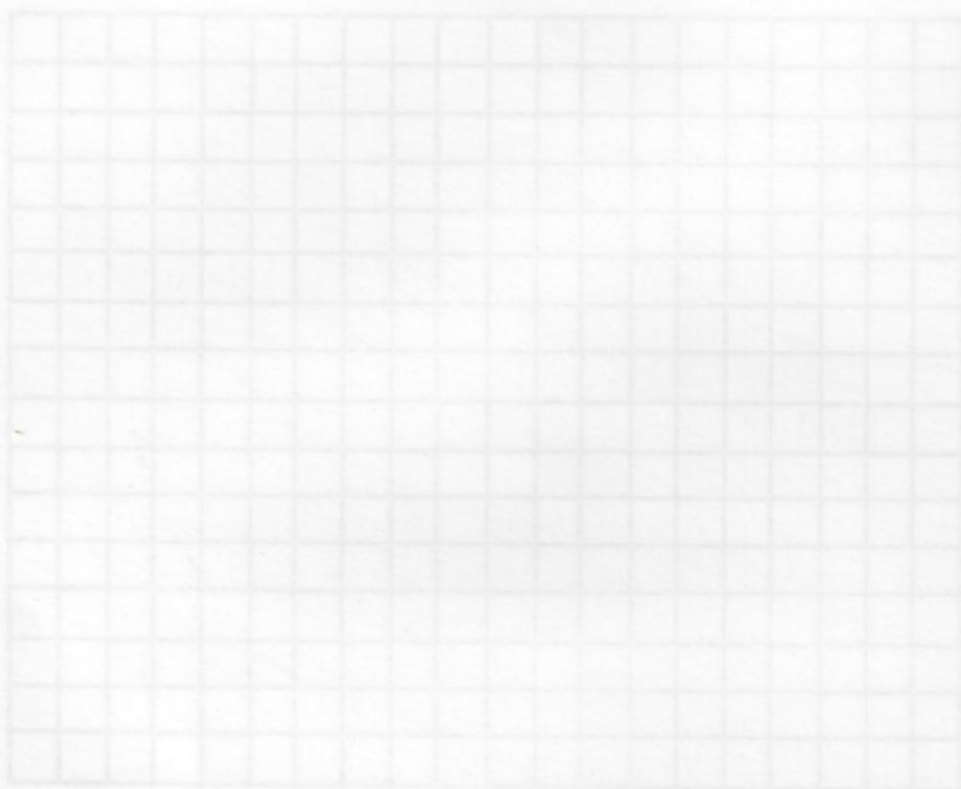


5 4 3 2 1 0 1 2 3 4 5
 - (MINUS) V_G + (PLUS) (change scale if desired)

6. Does the Gain of the amplifier vary with the bias voltage?
7. Varying the bias voltage, V_G , can be used to vary the gain automatically to result in a constant output level for different input levels. Such an automatic system is referred to as AGC or Automatic Gain Control.
8. At what Voltage, V_G , is the gain at a maximum? What is the maximum gain?

GAIN (maximum) =
V_G (setting for max. gain) =

4. Calculate the Gain and enter it in the table on preceding page.
5. Plot the transfer function.



GAIN

5
4
3
2
1
0
-1
-2
-3
-4
-5

-(MINUS) V_o + (PLUS) V_i (change scale if desired)

6. Does the Gain of the amplifier vary with the bias voltage?
7. Varying the bias voltage, V_b , can be used to vary the gain automatically in a closed loop for different input levels. Does an automatic system is referred to as AGC or Automatic Gain Control.
8. At what Voltage, V_b , is the gain at a maximum? What is the maximum gain?

GAIN (maximum) =
V_b (voltage for max. gain) =

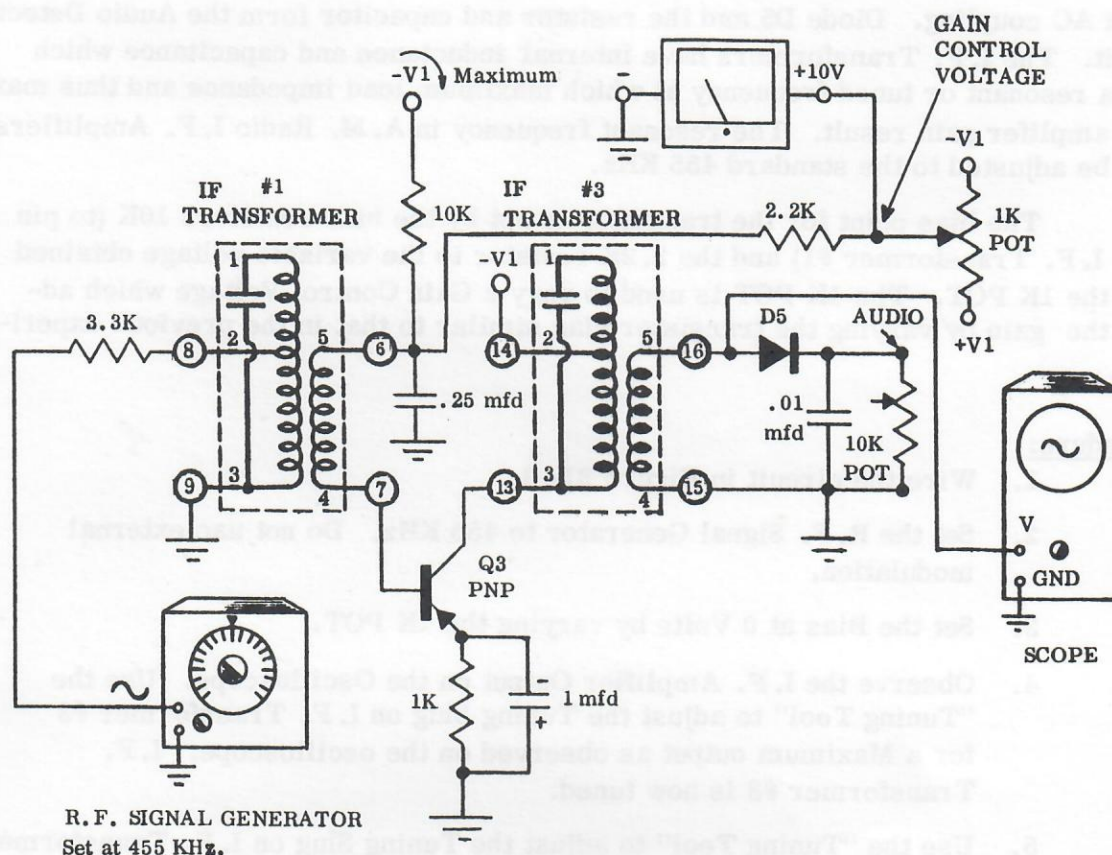


Figure 21-1 TUNED IF AMPLIFIER - EXPERIMENT

Objective:

You will test an IF Tuned Amplifier to determine the Gain Response as the Frequency is varied. You will measure the BANDWIDTH, ALIGN the tuned circuit, and measure the gain variation with a bias Gain Control Voltage which is used for AGC (Automatic Gain Control).

Description:

The I. F. Transformers provide coupling between the various amplifier stages. I. F. Transformer #1 is the input transformer to the amplifier which uses transistor Q3. I. F. Transformer #3 is in the collector as the load and also provides output AC coupling. Diode D5 and the resistor and capacitor form the Audio Detector circuit. The I. F. Transformers have internal inductance and capacitance which have a resonant or tuned frequency at which maximum load impedance and thus maximum amplifier gain result. The resonant frequency in A. M. Radio I. F. Amplifiers must be adjusted to the standard 455 KHz.

The bias point for the transistor is set by the bias resistors 10K (to pin 10 on I. F. Transformer #1) and the 2.2K resistor to the variable voltage obtained from the 1K POT. The 1K POT is used to vary a Gain Control Voltage which adjusts the gain by varying the transistor bias similar to that in the previous experiment.

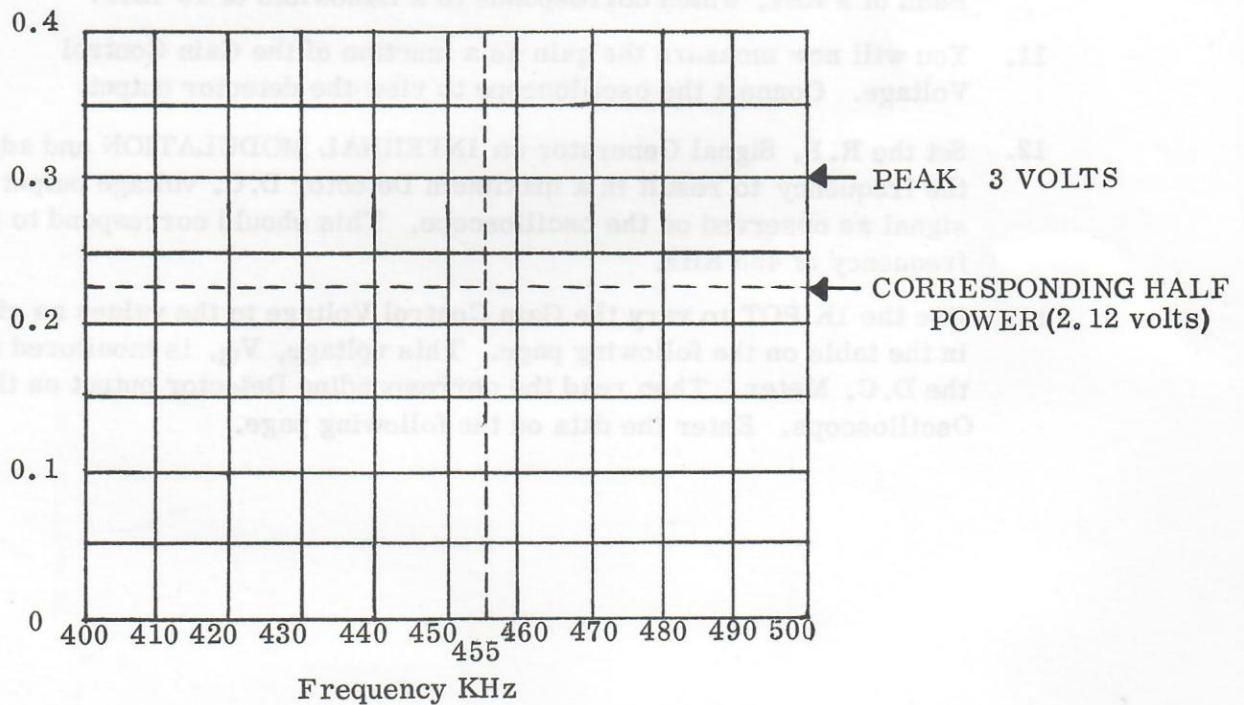
Procedure:

1. Wire the circuit in Figure 21-1.
2. Set the R. F. Signal Generator to 455 KHz. Do not use external modulation.
3. Set the Bias at 0 Volts by varying the 1K POT.
4. Observe the I. F. Amplifier Output on the Oscilloscope. Use the "Tuning Tool" to adjust the Tuning Slug on I. F. Transformer #3 for a Maximum output as observed on the oscilloscope. I. F. Transformer #3 is now tuned.
5. Use the "Tuning Tool" to adjust the Tuning Slug on I. F. Transformer #1 for a Maximum output on the Oscilloscope.
6. You will now plot the frequency response curve for the amplifier. Keep the R. F. Signal Generator at 455 KHz. Adjust the Signal Amplitude at a level where the output is 0.3 volts peak to peak. The output should not be distorted.
7. Set the R. F. Signal Generator at the frequencies given in the table below and enter the Peak-to-Peak Output Voltage reading on the oscilloscope.

Enter this output data in the table on the following page. (You may wish to connect the D. C. Meter to the Detector output and read the output on the Meter instead.)

Frequency KHz	Output Voltage
500	
490	
480	
470	
460	
455	
450	
440	
430	
420	
410	

8. Plot the frequency response below from the above table.



9. The curve on the previous page shows the "bandwidth" or the frequency response of the amplifier. The bandwidth is defined as the "width" at the half-power point. Because Power is equal to:

$$P = \frac{V^2}{R}$$

the Power is proportional to (V^2) , the square of the voltage.

Half-Power is thus at $\frac{V^2}{2R}$ or at the voltage of:

$$\frac{V}{\sqrt{2}} = \frac{V}{1.414} = .707V$$

For $V = 3$ volts; then:

$$\text{Half Power Voltage} = (.707)V = .707 (3) = 2.12 \text{ volts}$$

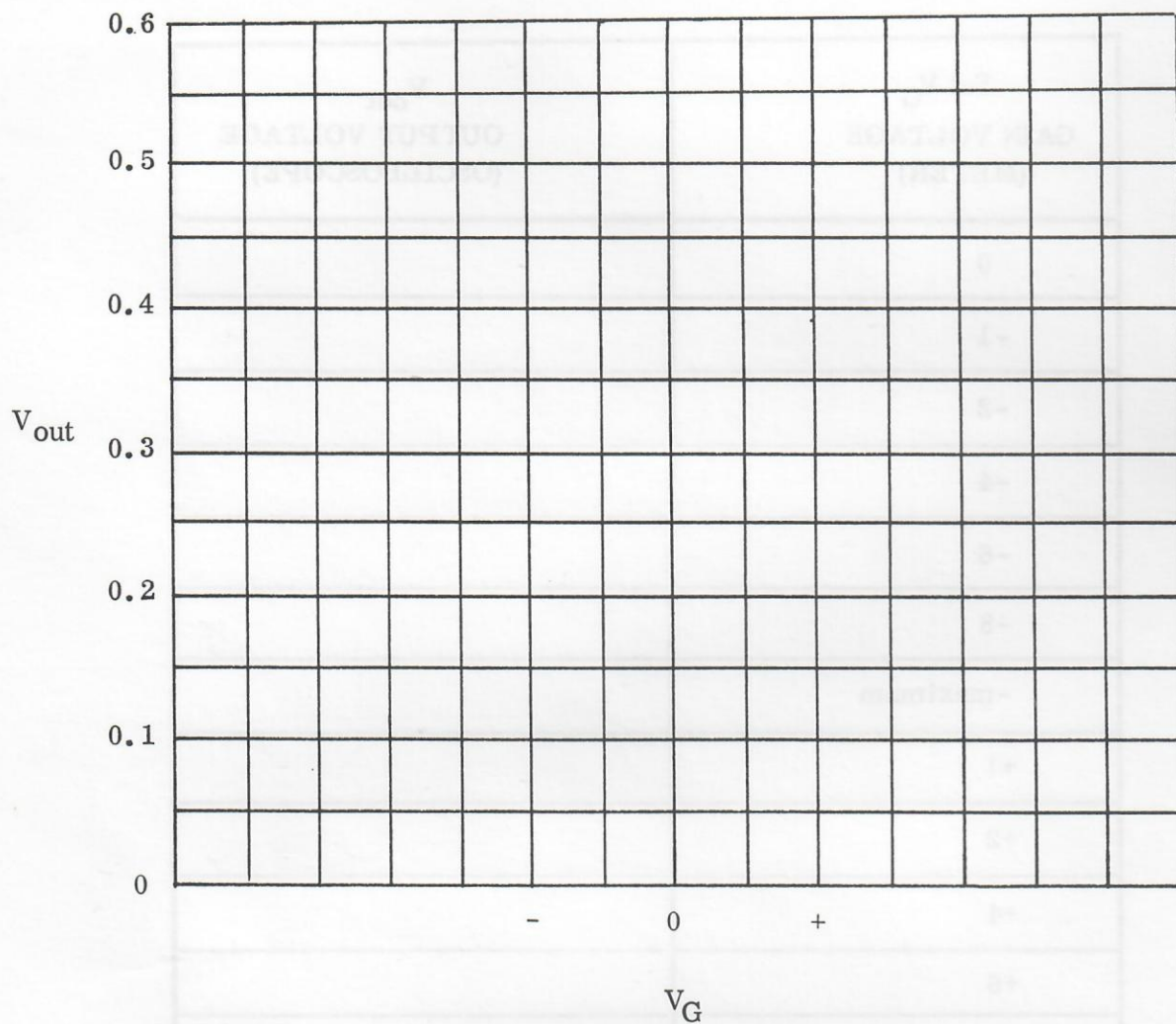
A line is drawn on the graph at the voltage of 2.12 volts. Measure the Bandwidth at the intersection of this line and the response curve. Enter this measured bandwidth below:

I. F. BANDWIDTH =	KHz
-------------------	-----

10. How does the above bandwidth correspond to the AM Radio Audio Band of 5 KHz, which corresponds to a Bandwidth of 10 KHz?
11. You will now measure the gain as a function of the Gain Control Voltage. Connect the oscilloscope to view the detector output.
12. Set the R.F. Signal Generator on INTERNAL MODULATION and adjust the frequency to result in a maximum Detector D.C. voltage output signal as observed on the oscilloscope. This should correspond to a frequency of 455 KHz.
13. Use the 1K POT to vary the Gain Control Voltage to the values as given in the table on the following page. This voltage, V_G , is monitored on the D.C. Meter. Then read the corresponding Detector output on the Oscilloscope. Enter the data on the following page.

Set V_G GAIN VOLTAGE (METER)	V_{out} OUTPUT VOLTAGE (OSCILLOSCOPE)
0	
-1	
-2	
-4	
-6	
-8	
-maximum	
+1	
+2	
+4	
+6	
+8	

14. Plot the output voltage (as a function of V_G , from the data measured in the above table.



15. At what control voltage, V_G , is the gain a maximum?

V_G (for maximum gain) =

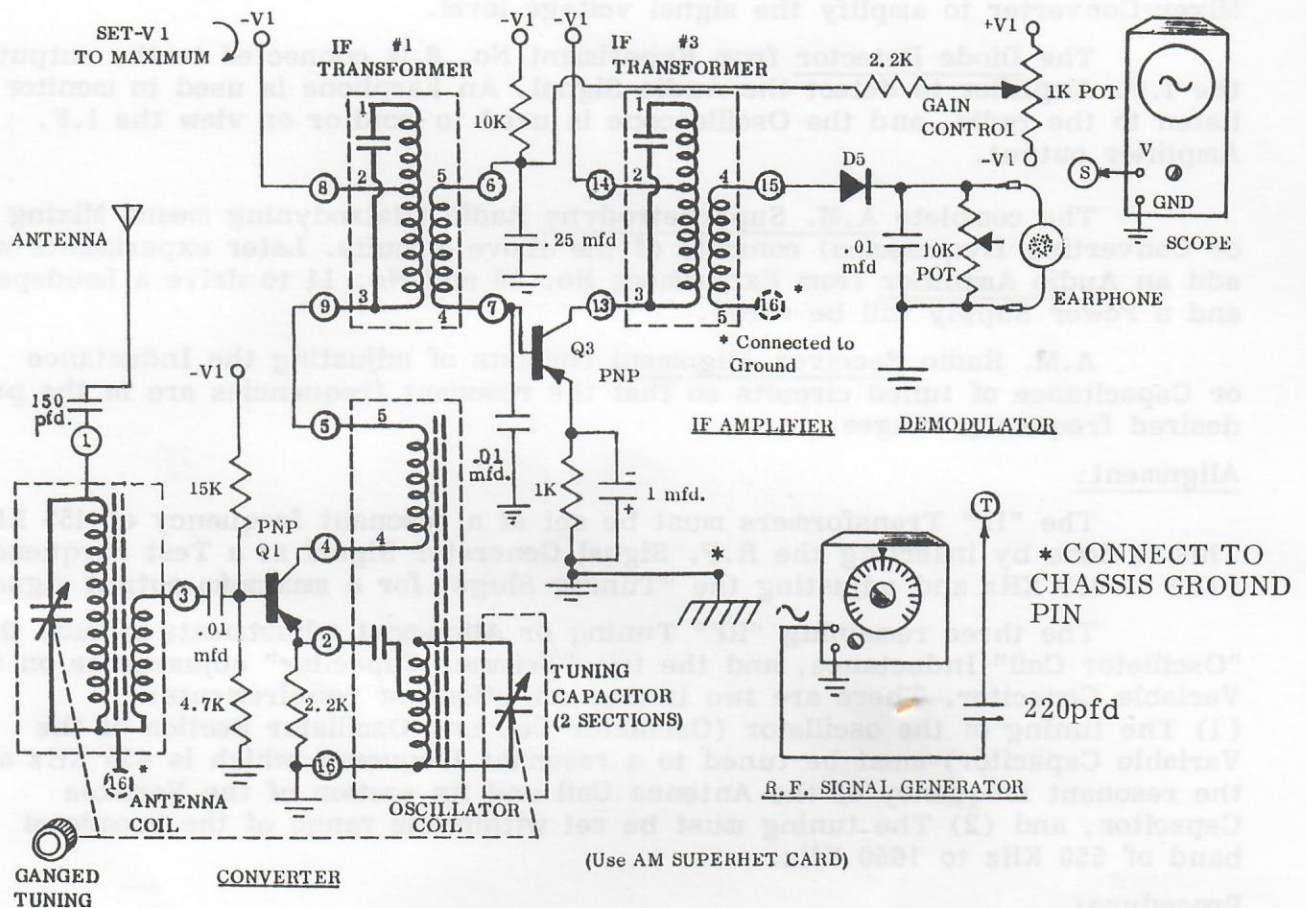


Figure 22-1 RECEIVER - ALIGNMENT-EXPERIMENT

Objective:

You will Align or Adjust the tuning components on an AM Superhetrodyne Receiver and you will then listen to various radio stations.

Description:

The Mixer-Converter from Experiment No. 19 converts the R.F. Radio Frequency as Selected or Tuned, to a 455 KHz Intermediate Frequency.

The I.F. Tuned Amplifier from Experiment No. 21 is connected to the Mixer-Converter to amplify the signal voltage level.

The Diode Detector from Experiment No. 8 is connected to the output of the I.F. Amplifier to detect the Audio Signal. An Earphone is used to monitor or listen to the radio, and the Oscilloscope is used to monitor or view the I.F. Amplifier output.

The complete A.M. Superhetrodyne Radio (Hetrodyning means Mixing or Converting frequencies) consists of the above circuits. Later experiments will add an Audio Amplifier from Experiment No. 10 and No. 11 to drive a Loudspeaker, and a Power Supply will be wired.

A.M. Radio Receiver Alignment consists of adjusting the Inductance or Capacitance of tuned circuits so that the resonant frequencies are in the proper desired frequency ranges.

Alignment:

The "IF" Transformers must be set at a resonant frequency of 455 KHz. This is done by inserting the R.F. Signal Generator Signal at a Test Frequency (TF) of 455 KHz and adjusting the "Tuning Slugs" for a maximum output signal.

The three remaining "RF" Tuning or Alignment adjustments include the "Oscillator Coil" Inductance, and the two "Trimmer Capacitor" adjustments on the Variable Capacitor. There are two tuning conditions or requirements:

(1) The tuning of the oscillator (Oscillator Coil and Oscillator Section of the Variable Capacitor) must be tuned to a resonant frequency which is 455 KHz above the resonant frequency of the Antenna Coil and its section of the Variable Capacitor, and (2) The tuning must be set within the range of the broadcast band of 550 KHz to 1650 KHz.

Procedure:

1. Insert the A.M. Radio Card in the Ed-Lab Printed Circuit Socket.
2. Wire the Radio circuit shown in Figure 22-1.
3. You will require an R.F. Signal Generator to apply test signals for the Radio Alignment.

The Alignment Procedure is described on the following page. Follow these steps to align the radio components.

You will need the Alignment Tool to adjust the coils.

NOTE: The correct tool must be used for the I.F. transformers and the Oscillator Coil. They are different sizes.

The Trimmer Capacitors are adjusted with a screw driver.

STEP 1 SET UP FOR I.F. AMPLIFIER ALIGNMENT

Set the R.F. Signal Generator Frequency to 455 KHz with the INTERNAL A.M. MODULATION ON.

Set the 1K GAIN POT to the MIDPOINT.

Connect the Capacitively Coupled R.F. Signal Generator Output lead "T" to PIN 9 of the Ed-Lab 650 P.C. Card Connector PIN #9 (Input to I.F. Transformer #1).

Connect a jumper wire (use a stacking lead) between Ed-Lab 650 P.C. Card Connector PINS 4 & 5 to disable the LOCAL OSCILLATOR.

Connect the Oscilloscope Input "S" to P.C. Card PIN #15 to monitor the I.F. Amplifier Output.

STEP 2 I.F. AMPLIFIER ALIGNMENT

Listen to the Earphone and observe the output signal on the Oscilloscope while performing this step.

Adjust the TUNING SLUGS on I.F. Transformers #1 and #3 for MAXIMUM AUDIO OUTPUT and LARGEST OSCILLOSCOPE SIGNAL.

NOTE: USE THE CORRECT ALIGNMENT TOOL AND BE CAREFUL. THE TUNING SLUGS ARE SOFT AND EASILY DAMAGED.

DO NOT USE FORCE

If the AUDIO OUTPUT is very loud or if there is any evidence of overdriving the I.F. Amplifier (Distortion or Clipping or Clamping) viewed on the Oscilloscope REDUCE THE SIGNAL LEVEL of the R.F. SIGNAL GENERATOR.

When the MAXIMUM SIGNAL OUTPUT is obtained the I.F. Transformers are adjusted.

STEP 3 OSCILLATOR COIL ALIGNMENT

Remove the jumper wire between P.C. Connector PINS 4 & 5.

Remove the R.F. SIGNAL GENERATOR lead "T" from P.C. Connector PIN 9 and connect to the ANTENNA TERMINAL (Remove the Antenna before this connection is made.)

Remove the Oscilloscope Input lead "S" from P.C. Connector PIN 15 and Connect to P.C. Connector PIN 4.

Set the SUPERHET CARD TUNING CAPACITOR to HALF MESHED.

Adjust the OSCILLATOR COIL TUNING SLUG FOR MAXIMUM AUDIO OUTPUT HEARD ON THE EARPHONE.

NOTE: USE THE CORRECT ALIGNMENT TOOL AND DO NOT FORCE THE SLUG

If the Oscillator Coil Slug is TOO FAR OUT or TOO FAR IN then the TRIMMER CAPACITOR SCREW on the SMALL SECTION OF THE TUNING CAPACITOR may be adjusted to change the MAXIMUM POSITION for the Oscillator Coil Tuning Slug.

Rotate the Tuning Capacitor slowly throughout its range. The LOCAL OSCILLATOR signal viewed on the Oscilloscope should change gradually throughout the range of adjustment of the Variable Tuning Capacitor.

STEP 4 FINAL OSCILLATOR ADJUSTMENT

Set the R.F. Signal Generator to 600 KHz.

Disconnect the Oscilloscope Input lead.

Adjust the Variable Tuning Capacitor until the Maximum signal is heard on the earphone.

Adjust the OSCILLATOR TRIMMER CAPACITOR SCREW on the bottom of the Variable Capacitor at the Small Capacitor Section for MAXIMUM AUDIO OUTPUT.

STEP 5 TUNING RANGE TEST

If desired, the student may check to see that the Radio is tuned over the entire range by measurements at 550 KHz and 1600 KHz. This is accomplished by setting the R.F. Signal Generator frequency at 550 KHz, and checking to see that the "low-end" of the band is received when the tuning capacitor is rotated where the plates are approximately fully meshed (highest capacitance results in lowest frequency). If the tuning cannot reach the end of the band, then a re-adjustment of the oscillator tuning coil and the tuning variable Capacitor trimmer would be indicated. It is not necessary to make this fine adjustment.

END OF ALIGNMENT PROCEDURE

4. Remove the Signal Generator lead and connect an Antenna wire. The antenna should be set outside of the building and should be about 20 feet long for good reception in a metal building. You could also try a 10 foot antenna connected directly at the trainer. You could also try using a simple "connection lead" as the antenna and "touch" the lead with your hand so that your body acts as the antenna. The short antenna may be adequate to receive strong Radio Stations.
5. Tune the Radio to various Radio Stations by rotating the variable Capacitor tuning knob. Select one station and summarize the Program subject in one sentence below.

END OF ALIGNMENT PROCEDURE

4. Remove the Signal Generator lead and connect an antenna wire. The antenna should be set outside of the building and should be about 30 feet long for good reception in a metal building. You could also try a 10 foot antenna connected directly at the trainer. You could also try using a simple "connection lead" as the antenna and "touch" the lead with your hand so that your body acts as the antenna. The short antenna may be adequate to receive strong Radio Stations.
5. Tune the Radio to various Radio Stations by rotating the variable Capacitor tuning knob. Select one station and summarize the program subject in one sentence below.

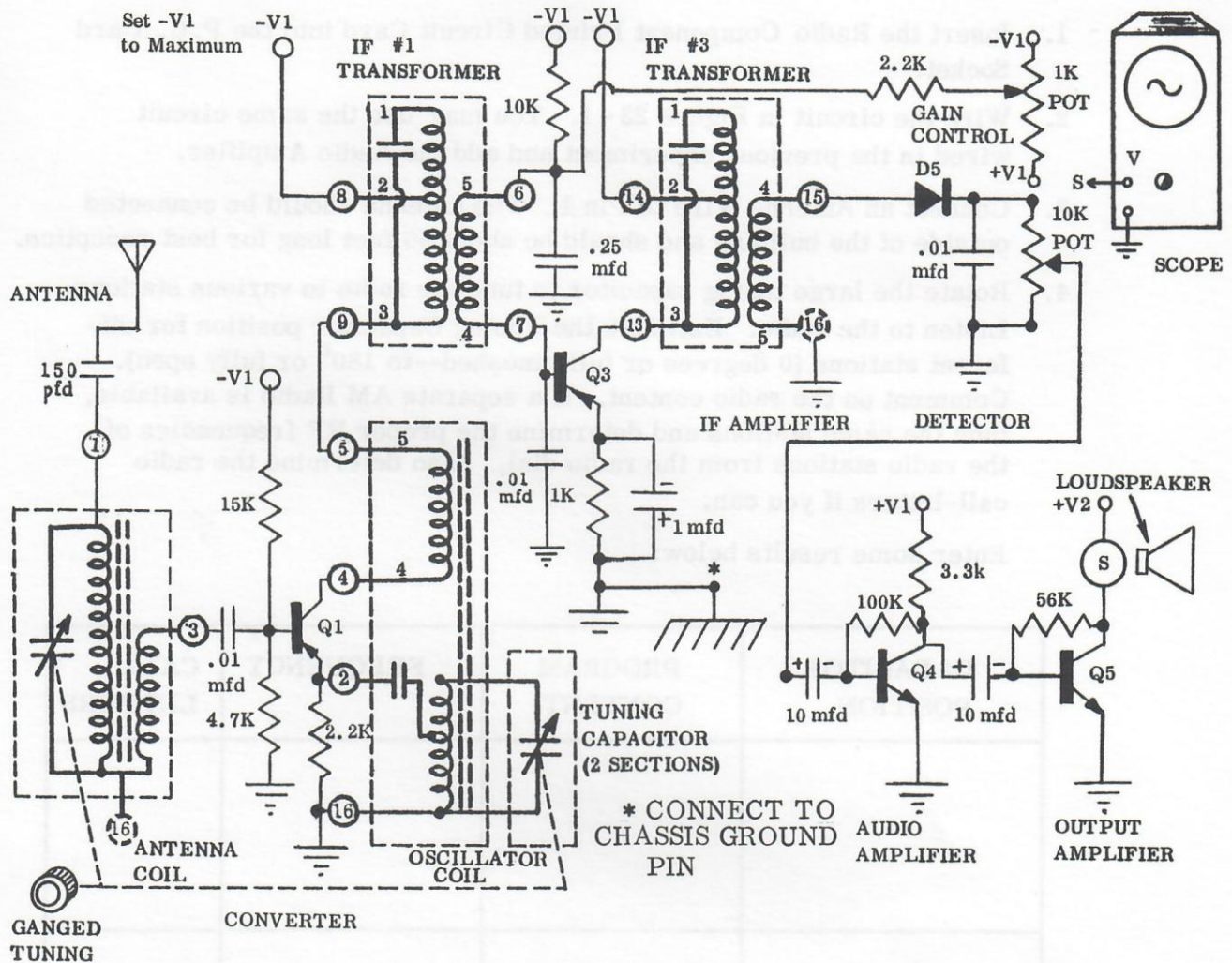


Figure 23-1 AM RADIO & AMPLIFIER - EXPERIMENT

Objective:

You will connect the SUPERHET Receiver to an Audio Amplifier and tune in various radio station.

Description:

The radio circuit uses the same Converter-IF Amplifier-Detector Superhet from the previous experiment and adds the Two-Stage Audio Amplifier from another previous experiment.

Procedure:

1. Insert the Radio Component Printed Circuit Card into the P.C. Card Socket.
2. Wire the circuit in Figure 23 - 1. You may use the same circuit wired in the previous experiment and add the Audio Amplifier.
3. Connect an Antenna Wire to Pin 1. The antenna should be connected outside of the building and should be about 50 feet long for best reception.
4. Rotate the large tuning capacitor to tune the radio to various stations. Listen to the radio. Estimate the Tuning Capacitor position for different stations (0 degrees or fully meshed--to 180° or fully open). Comment on the radio content. If a separate AM Radio is available, tune the same stations and determine the proper RF frequencies of the radio stations from the radio dial. Also determine the radio call-letters if you can.

Enter some results below:

CAPACITOR POSITION	PROGRAM CONTENT	FREQUENCY	CALL LETTERS

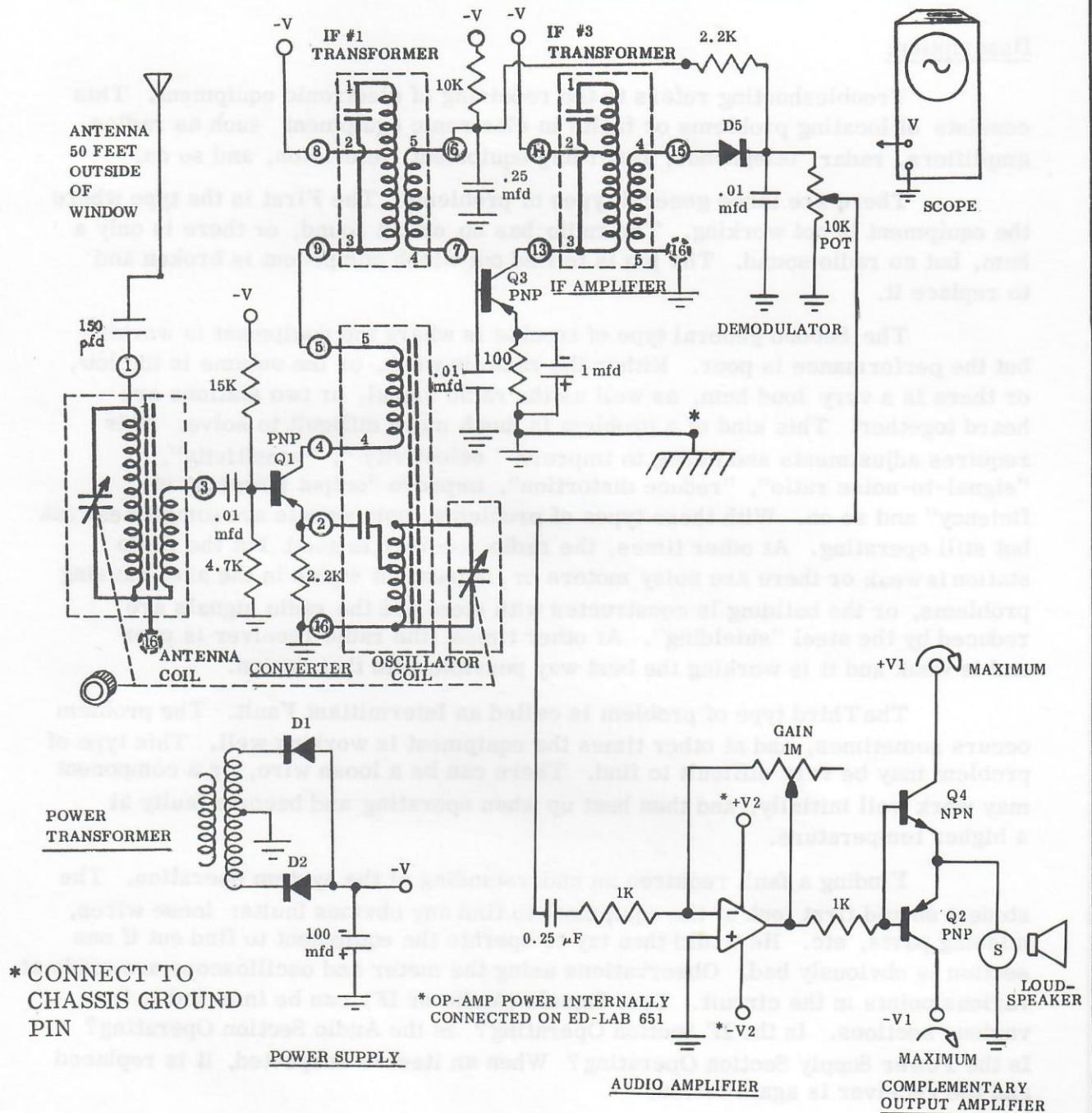


Figure 24 - 1 RECEIVER - TROUBLESHOOTING-EXPERIMENT

Objective:

You will wire a Superhetrodyne Radio Receiver with an output audio amplifier and a complementary transistor loudspeaker driver. The instructor will place a fault or trouble in the radio and you will "troubleshoot" and test the radio to determine where the fault is located. You will then repair the radio.

Description:

Troubleshooting refers to the repairing of electronic equipment. This consists of locating problems or faults in electronic equipment such as radios, amplifiers, radar, telephones, recording equipment, television, and so on.

There are three general types of problems: The First is the type where the equipment is not working. The radio has no output sound, or there is only a hum, but no radio sound. The job is to find out which component is broken and to replace it.

The Second general type of trouble is where the equipment is working but the performance is poor. Either the radio is weak, or the volume is too low, or there is a very loud hum, as well as the radio signal, or two stations are heard together. This kind of a problem is much more difficult to solve. This requires adjustments and tuning to improve "selectivity", "sensitivity", "signal-to-noise ratio", "reduce distortion", improve "output power or efficiency" and so on. With these types of problems, components are sometimes weak but still operating. At other times, the radio receiver is good, but the radio station is weak or there are noisy motors or fluorescent lights in the area causing problems, or the building is constructed with steel and the radio signals are reduced by the steel "shielding". At other times, the radio receiver is poor and is weak and it is working the best way possible with that design.

The Third type of problem is called an Intermittant Fault. The problem occurs sometimes, and at other times the equipment is working well. This type of problem may be very difficult to find. There can be a loose wire, or a component may work well initially, and then heat up when operating and become faulty at a higher temperature.

Finding a fault requires an understanding of the system operation. The student should first look at the equipment to find any obvious faults: loose wires, missing parts, etc. He would then try to operate the equipment to find out if one section is obviously bad. Observations using the meter and oscilloscope are made at various points in the circuit. Test Signals (Audio or IF) can be inserted to test various sections. Is the IF Section Operating? Is the Audio Section Operating? Is the Power Supply Section Operating? When an item is suspected, it is replaced and the receiver is again tested.

The Radio Receiver in Figure 24 - 1 includes a Complementary Output Driver and a Power Supply as well as the Superhet Radio.

Procedure:

1. Wire the circuit in Figure 24 - 1.
2. Test the receiver to see that it is operating. Check below:

RECEIVER TEST Okay ☐
--

3. Call the instructor to insert a trouble.
4. After the instructor has inserted a trouble, or more than one trouble, TROUBLESHOOT and fix the problem. Enter the various troubles and comments below:

PROBLEM	TROUBLE REPAIRED	COMMENTS
1		
2		
3		
4		
5		

3. Call the instructor to insert a trouble.
4. After the instructor has inserted a trouble, or more than one trouble, TROUBLESHOOT and fix the problem. Enter the various troubles and comments below:

PROBLEM	TROUBLE REPAIRED	COMMENTS
1		
2		
3		
4		
5		

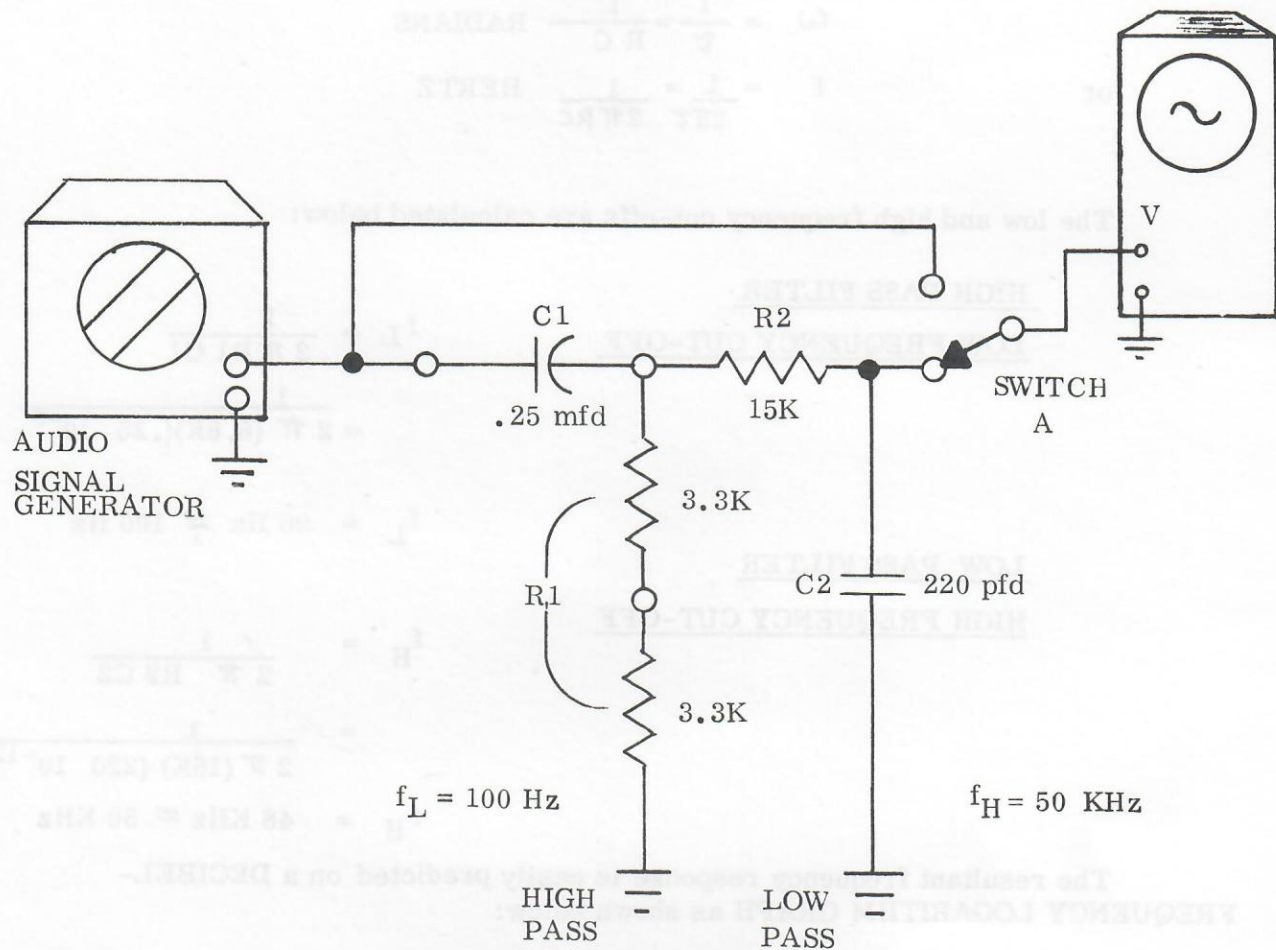


Figure 25 - 1 Bandpass Filter

Objective:

You will build a Bandpass Filter that will pass mid-frequencies and reject lower and higher frequencies. You will plot the results on "semilog" graph paper.

Description:

A series circuit capacitor, C1, blocks D.C. and results in a high-pass filter. A shunt or output parallel capacitor, C2, results in a low-pass filter. The "cut-off frequencies" can be easily predicated and calculated using the time constant, τ , where :

$$\tau = R \cdot C$$

The cut-off frequency is given by:

$$\omega = \frac{1}{\tau} = \frac{1}{R C} \text{ RADIANS}$$

or
$$f = \frac{1}{2\pi\tau} = \frac{1}{2\pi R C} \text{ HERTZ}$$

The low and high frequency cut-offs are calculated below:

HIGH PASS FILTER

LOW FREQUENCY CUT-OFF

$$f_L = \frac{1}{2\pi R_1 C_1}$$

$$= \frac{1}{2\pi (6.6K)(.25 \cdot 10^{-6})}$$

$$f_L = 96 \text{ Hz} \approx 100 \text{ Hz}$$

LOW PASS FILTER

HIGH FREQUENCY CUT-OFF

$$f_H = \frac{1}{2\pi R_2 C_2}$$

$$= \frac{1}{2\pi (15K)(220 \cdot 10^{-12})}$$

$$f_H = 48 \text{ KHz} \approx 50 \text{ KHz}$$

The resultant frequency response is easily predicted on a DECIBEL-FREQUENCY LOGARITHM GRAPH as shown below:

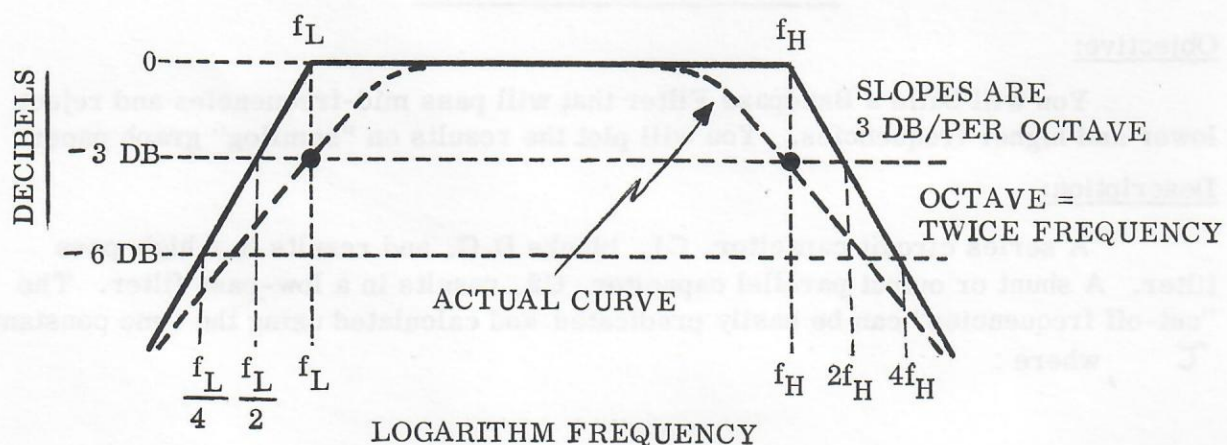


Figure 25 - 2 Ideal Bandpass Response

Decibels and Logarithms are discussed in detail in many reference texts. They relate to "exponentials" which correspond to the natural responses in electronics. Plotting curves in Logarithms or Decibels (which are logarithms of ratios of output to input), result in simple straight lines

The DECIBEL (db) is defined as the logarithm of the ratio of POWER (P):

$$DB = 10 \log_{10} \frac{P_{\text{output}}}{P_{\text{input}}}$$

$$\text{or } DB = 20 \log_{10} \frac{V_{\text{output}}}{V_{\text{input}}} \quad (V \text{ is Voltage})$$

A reduction in output of 3 DECIBELS corresponds to HALF-POWER and this occurs at the cut-off frequencies.

$$\text{POWER} \quad P = \frac{V^2}{R}$$

$$\text{HALF-POWER} \quad \frac{1}{2} P = \frac{1}{2} \frac{V^2}{R}$$

$$\frac{1}{2} P = \left(\frac{V}{\sqrt{2}} \right)^2 \frac{1}{R}$$

Where the full Power Output Voltage is V, the half-power output voltage is at: $V/\sqrt{2}$ For V = 6 VOLTS; Half-power is $V_H = 6/1.4 = 4$ VOLTS. These half-power points are plotted on the graph in the procedure section in Paragraph 6.

It is not possible to plot a wide-band pass response on a single "linear" graph because the upper or lower end of the curve will be "squeezed". A logarithm horizontal frequency plot is thus needed. Using decibels and logarithms and time constants, it is easy to calculate and estimate the shape of simple as well as very complex filter circuits.

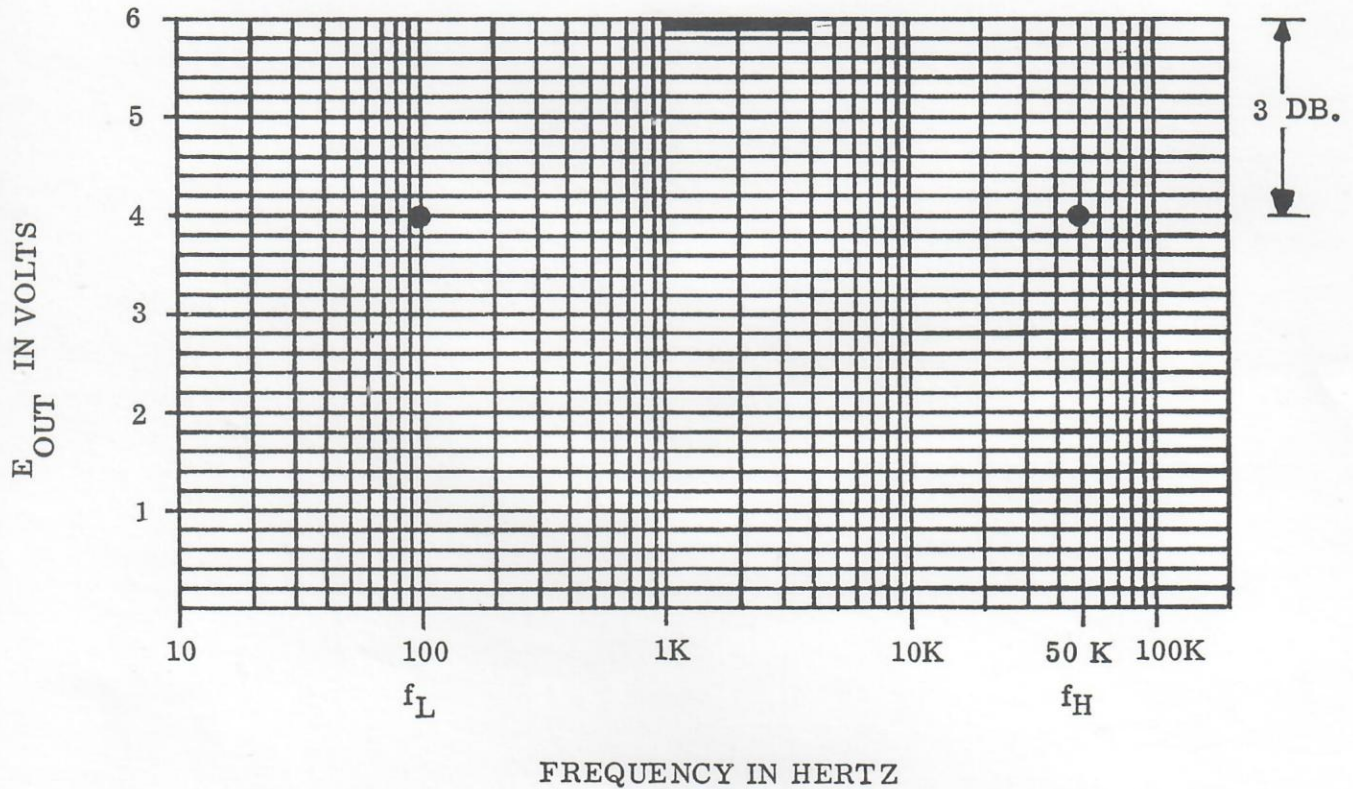
Procedure:

1. Wire the Band-Pass Filter circuit in Figure 25 - 1.
2. Set the Audio Generator Frequency at the first of the frequencies in the chart on the following page (20 Hertz).
3. Set Switch A in the UP position to observe the INPUT on the oscilloscope. Adjust the amplitude of the sinewaves to 6 volts peak-to-peak.
4. Set Switch A in the DOWN position and measure the amplitude of the output (peak to peak) on the oscilloscope. Record this data in the chart.

5. Set the Audio Generator to the next frequencies on the chart. Be sure to set Switch A UP each time to set the input voltage to 6 volts peak-to-peak, before reading the output voltage with Switch A DOWN. Enter all data in the table below :

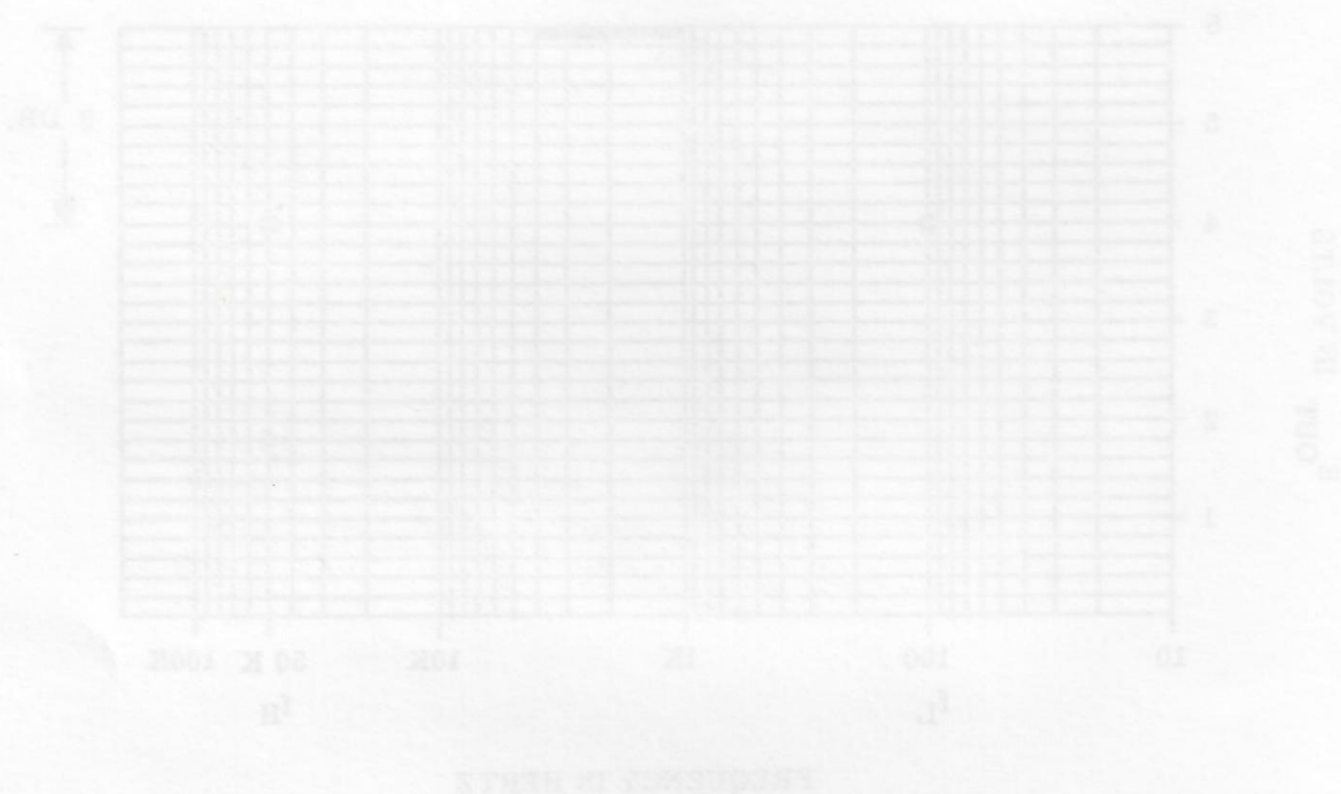
FREQUENCY	OUTPUT VOLTAGE (Peak - to - Peak)
20 Hz	
50 Hz	
100 Hz	
200 Hz	
500 Hz	
1000 Hz	
2000 Hz	
5000 Hz	
10 KHz	
20 KHz	
40 KHz	
50 KHz	
100 KHz	
200 KHz	

6. Plot the results in the graph below. The black dots indicate the predicted results based on the Resistor and Capacitance Time Constants (3 DB DOWN AT THE CUT-OFF FREQUENCIES).



7. How do the actual results compare with the anticipated results?

6. Plot the results in the graph below. The black dots indicate the predicted results based on the Resistor and Capacitor Time Constants. Be down at the cut-off frequency.



7. How do the actual results compare with the anticipated results?

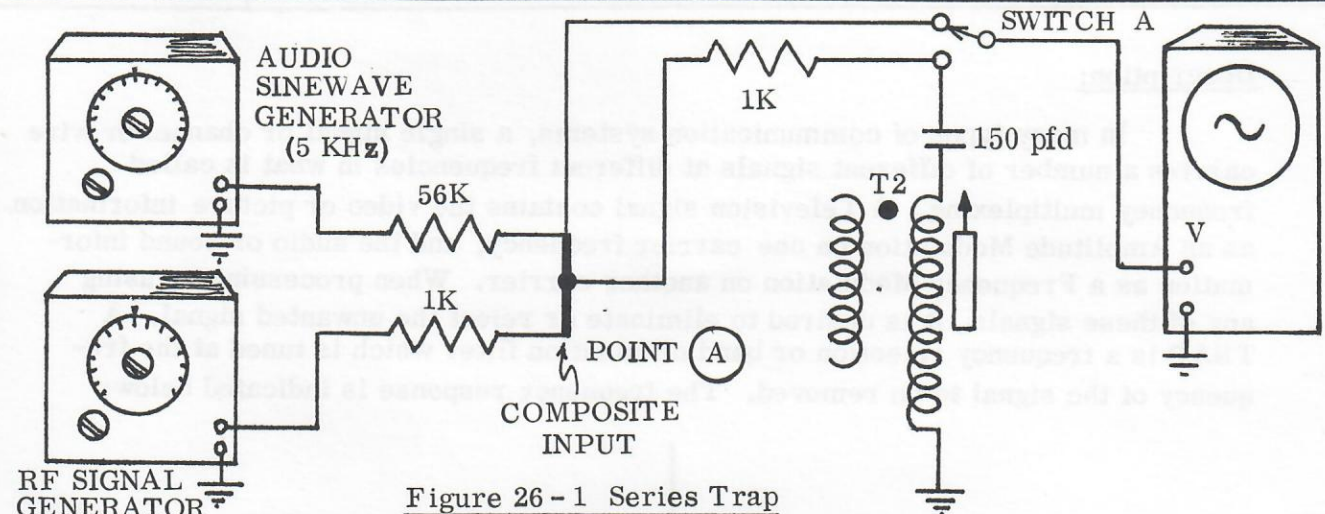


Figure 26 - 1 Series Trap

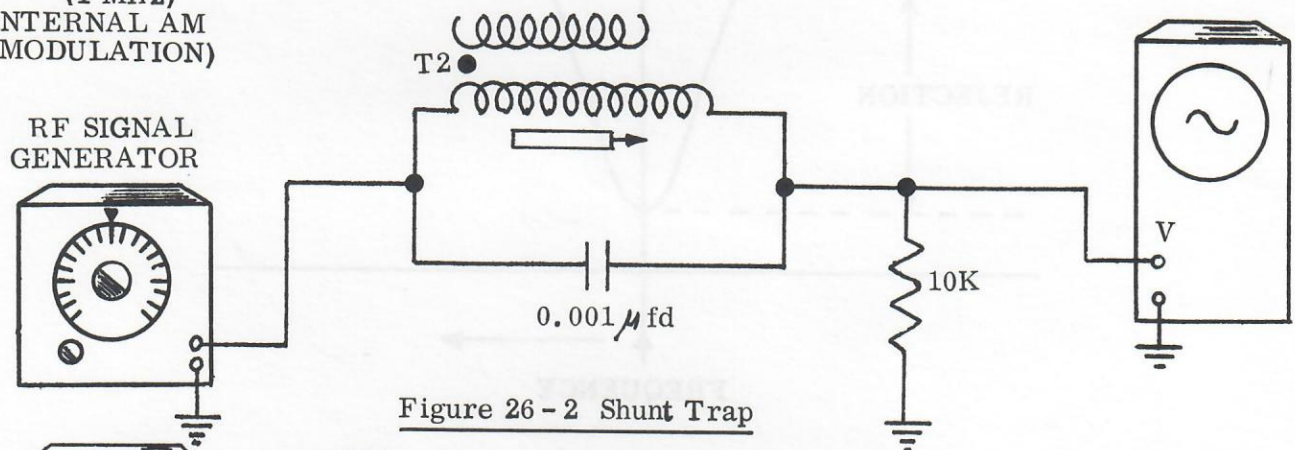


Figure 26 - 2 Shunt Trap

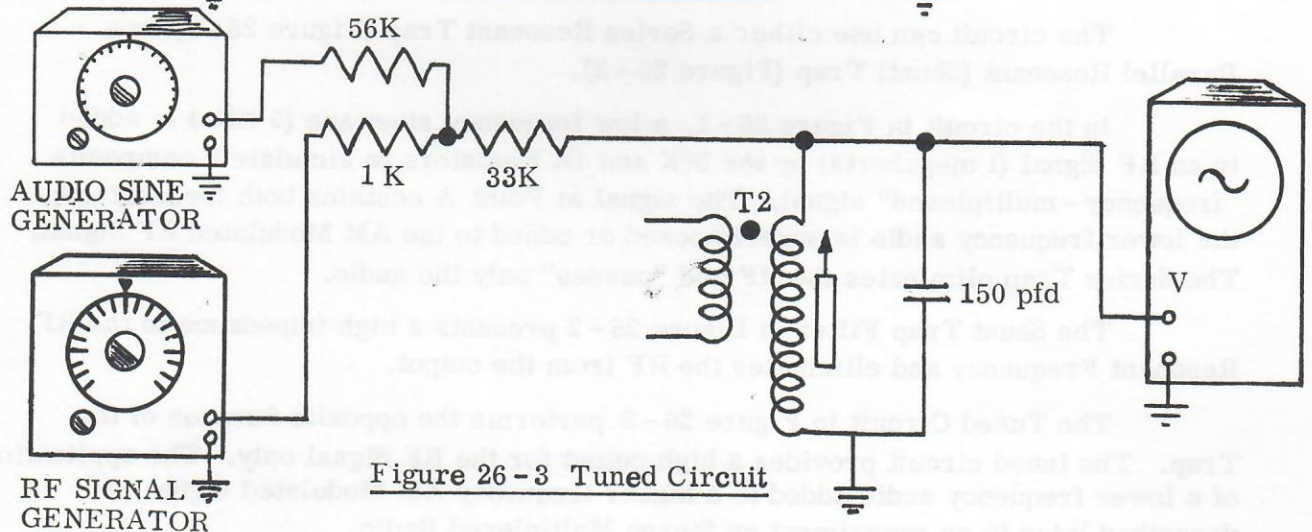


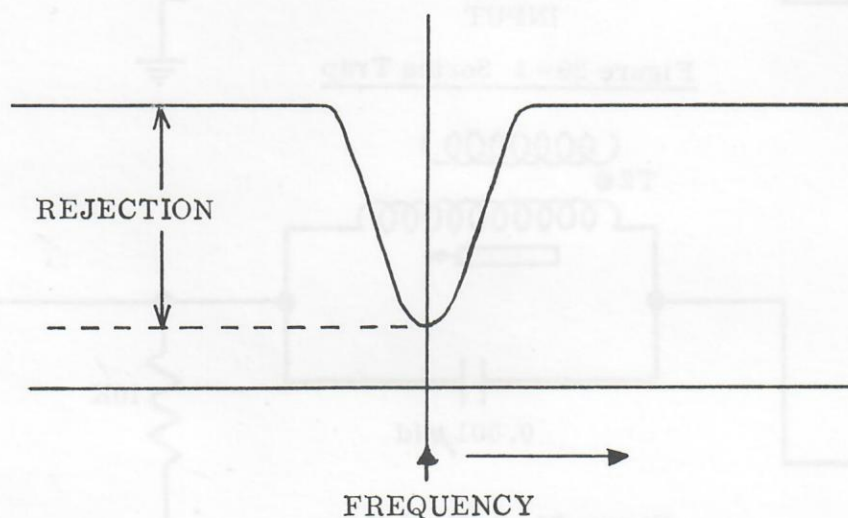
Figure 26 - 3 Tuned Circuit

Objective:

You will measure the frequency response of Frequency Trap Filters using Series and Parallel Circuits. You will also determine the response of a Frequency Pass Filter consisting of a Tuned Parallel Resonant Circuit.

Description:

In many types of communication systems, a single signal or channel or wire carries a number of different signals at different frequencies in what is called frequency multiplexing. A Television signal contains the video or picture information as an Amplitude Modulation on one carrier frequency, and the audio or sound information as a Frequency Modulation on another carrier. When processing or using any of these signals, it is desired to eliminate or reject the unwanted signal. A TRAP is a frequency rejection or band elimination filter which is tuned at the frequency of the signal to be removed. The frequency response is indicated below:



The circuit can use either a Series Resonant Trap (Figure 26 - 1) or a Parallel Resonant (Shunt) Trap (Figure 26 - 2).

In the circuit in Figure 26 - 1, a low frequency sinewave (5 KHz) is added to an RF Signal (1 megahertz) by the 56K and 1K Resistors to simulate a composite "frequency - multiplexed" signal. The signal at Point A contains both frequencies; the lower frequency audio is superimposed or added to the AM Modulated RF Signal. The Series Trap eliminates the RF and "passes" only the audio.

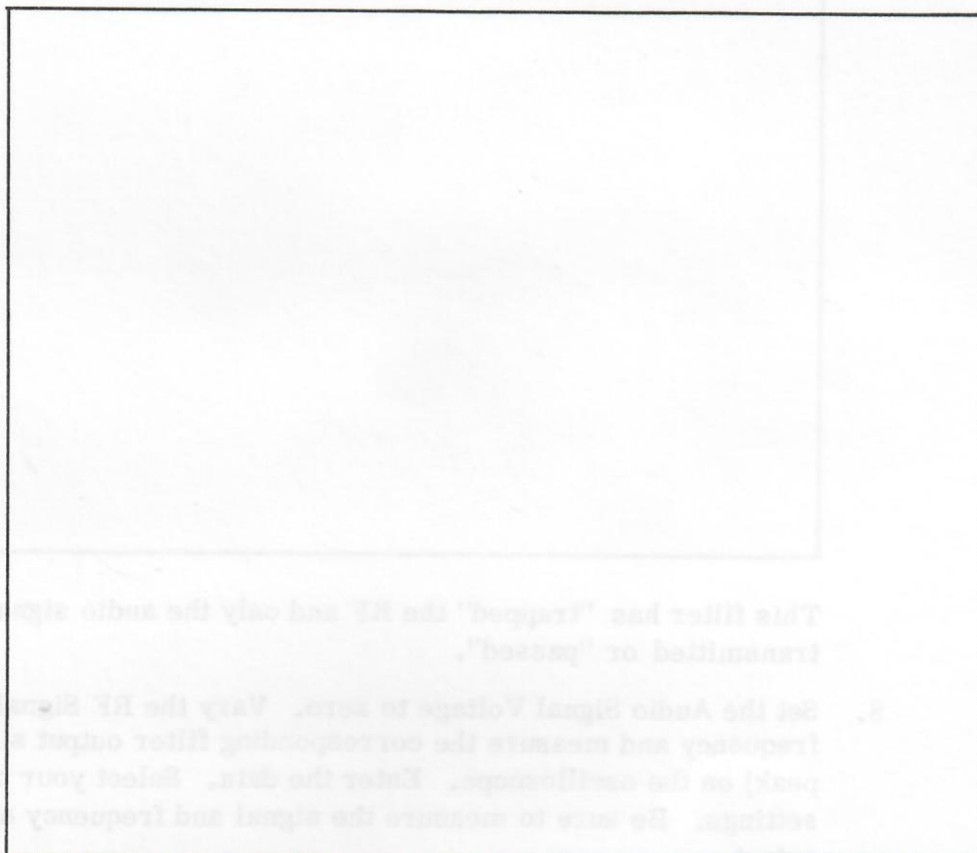
The Shunt Trap Filter in Figure 26 - 2 presents a high impedance to the RF Resonant Frequency and eliminates the RF from the output.

The Tuned Circuit in Figure 26 - 3 performs the opposite function of the Trap. The tuned circuit provides a high output for the RF Signal only. The application of a lower frequency audio added to a higher frequency AM Modulated signal is described later in an experiment on Stereo Multiplexed Radio.

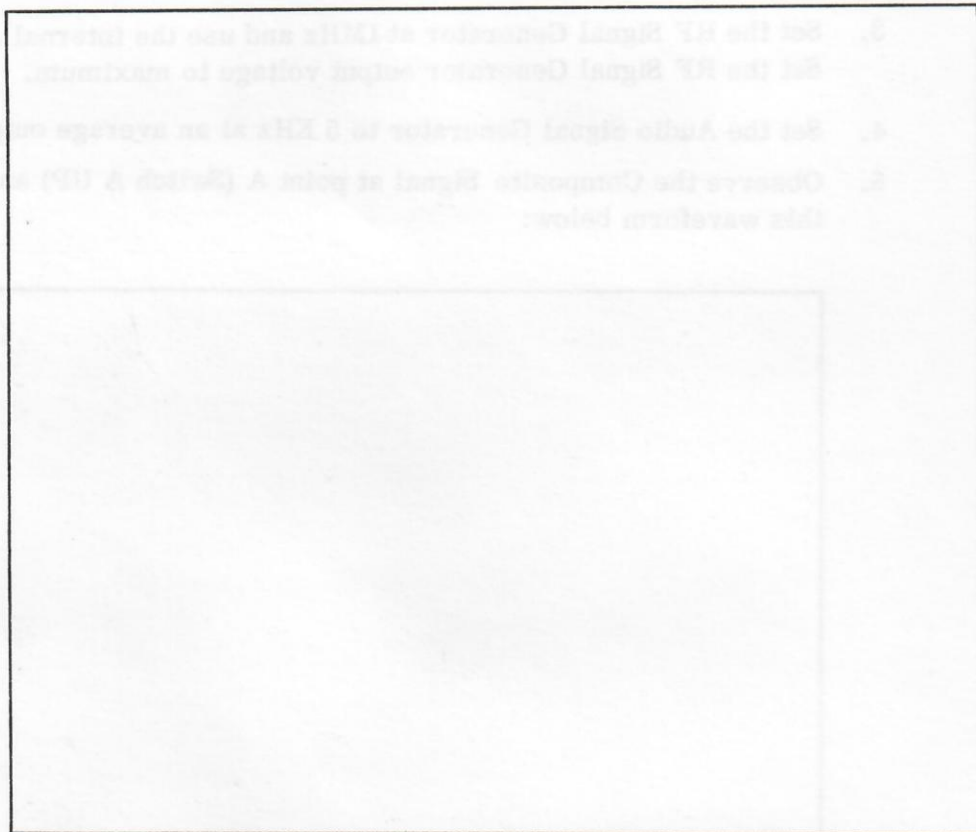
Procedure:

1. Wire the circuit in Figure 26 - 1.
2. Set Switch A UP to view the Composite input signal.

3. Set the RF Signal Generator at 1MHz and use the internal AM Modulation. Set the RF Signal Generator output voltage to maximum.
4. Set the Audio Signal Generator to 5 KHz at an average output voltage.
5. Observe the Composite Signal at point A (Switch A UP) and sketch this waveform below:



6. Set Switch A DOWN to observe the Series Trap Filter Output. Adjust the RF Coil Tuning Knob to tune the filter or trap at the RF 1 MHz signal (or you can adjust the RF Signal Generator Frequency) to result in a minimum RF output.
7. Observe the filter output and observe that the RF Signal is reduced or "attenuated". Sketch the output on the following page:



This filter has "trapped" the RF and only the audio signal is transmitted or "passed".

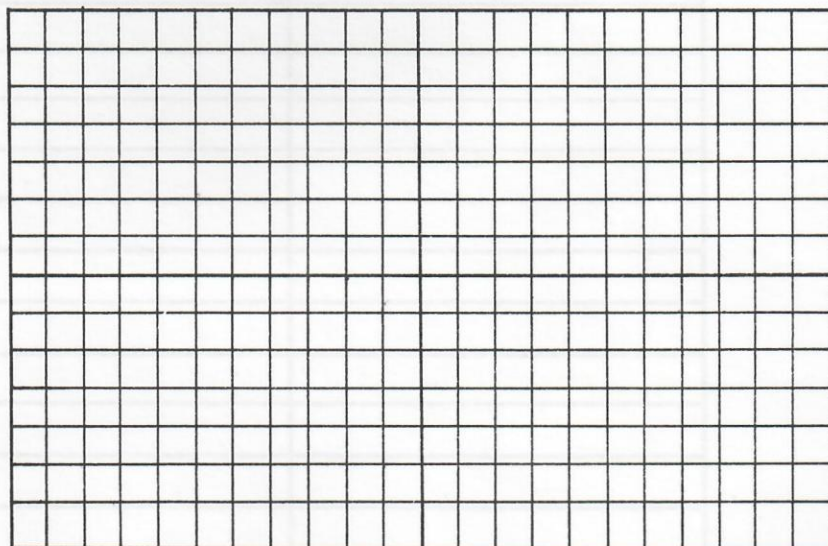
8. Set the Audio Signal Voltage to zero. Vary the RF Signal Generator frequency and measure the corresponding filter output signal (peak-to-peak) on the oscilloscope. Enter the data. Select your own frequency settings. Be sure to measure the signal and frequency at the lowest output.

Check the input signal amplitude for each frequency tested and set the R.F. Generator amplitude for the same level for each frequency used. Take data from 100 KHz to 2.0 MHz in 100 KHz increments.

[illegible]

9. Plot the results Below:

OUTPUT
(PEAK-TO-PEAK
VOLTAGE)



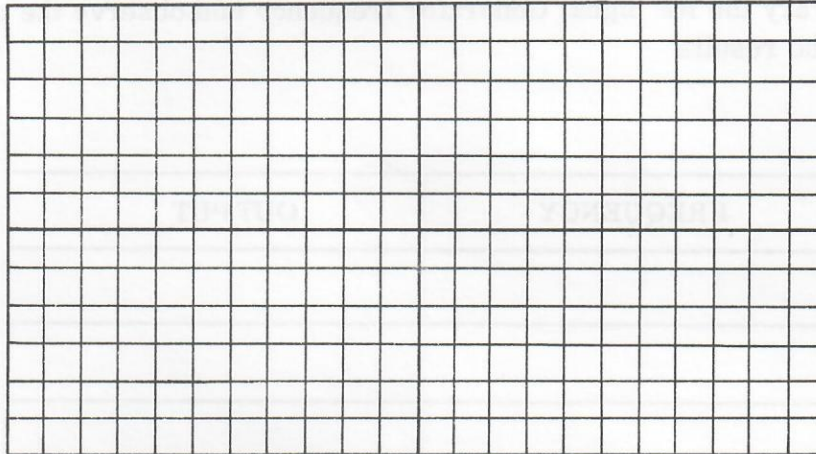
FREQUENCY

$$\text{REJECTION} = \frac{\text{MINIMUM VOLTAGE}}{\text{NOMINAL OUTPUT}} = \underline{\hspace{2cm}}$$

REJECTION = DECIBELS.

- [illegible]

OUTPUT



FREQUENCY

13. Calculate the Filter Rejection:

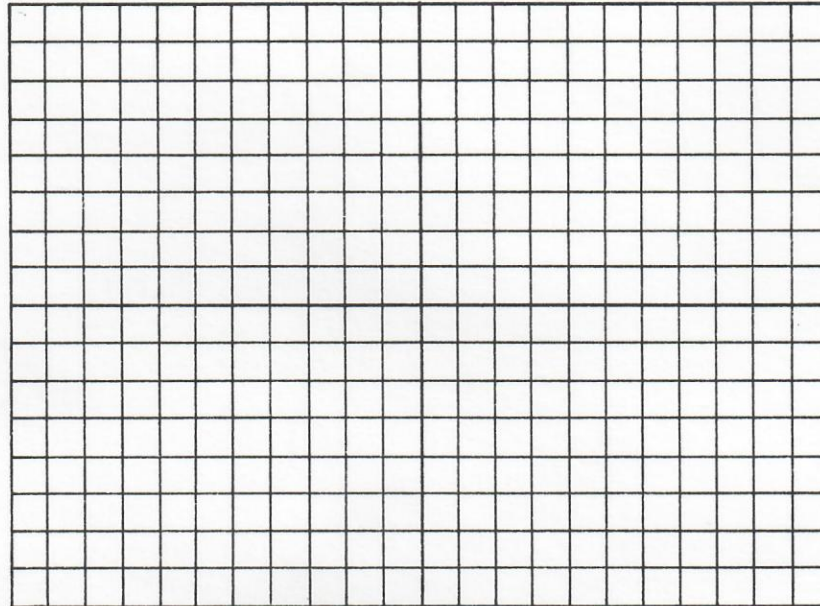
REJECTION =

14. Wire the Tuned Circuit in Figure 26 - 3. Set the RF Signal Generator at 1 MHz with internal AM Modulation and at maximum signal level. Set the Audio Sinewave Generator at 5 KHz. Observe the output signal. Vary the Tuning Knob to tune the Filter for maximum output. Observe that the Audio Signal is attenuated at the output. Sketch the waveform below:



Plot the results below:

OUTPUT

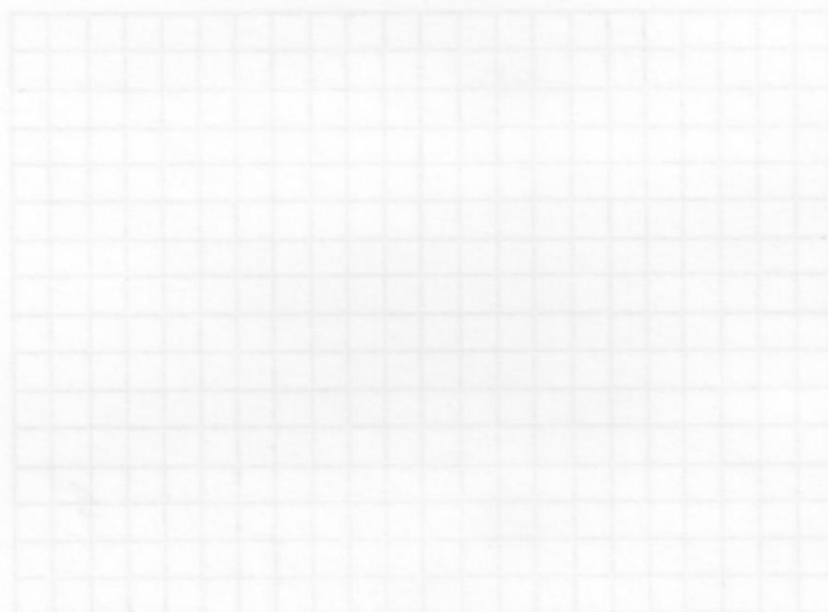


FREQUENCY

16. Calculate the Filter Attenuation (out of pass band). Calculate the results in Decibels.

TUNED CIRCUIT ATTENUATION = DB.

Plot the results below:



OUTPUT

FREQUENCY

16. Calculate the Filter Attenuation (out of pass band). Calculate the results in Decibels.

TUNED CIRCUIT ATTENUATION = _____ DB.

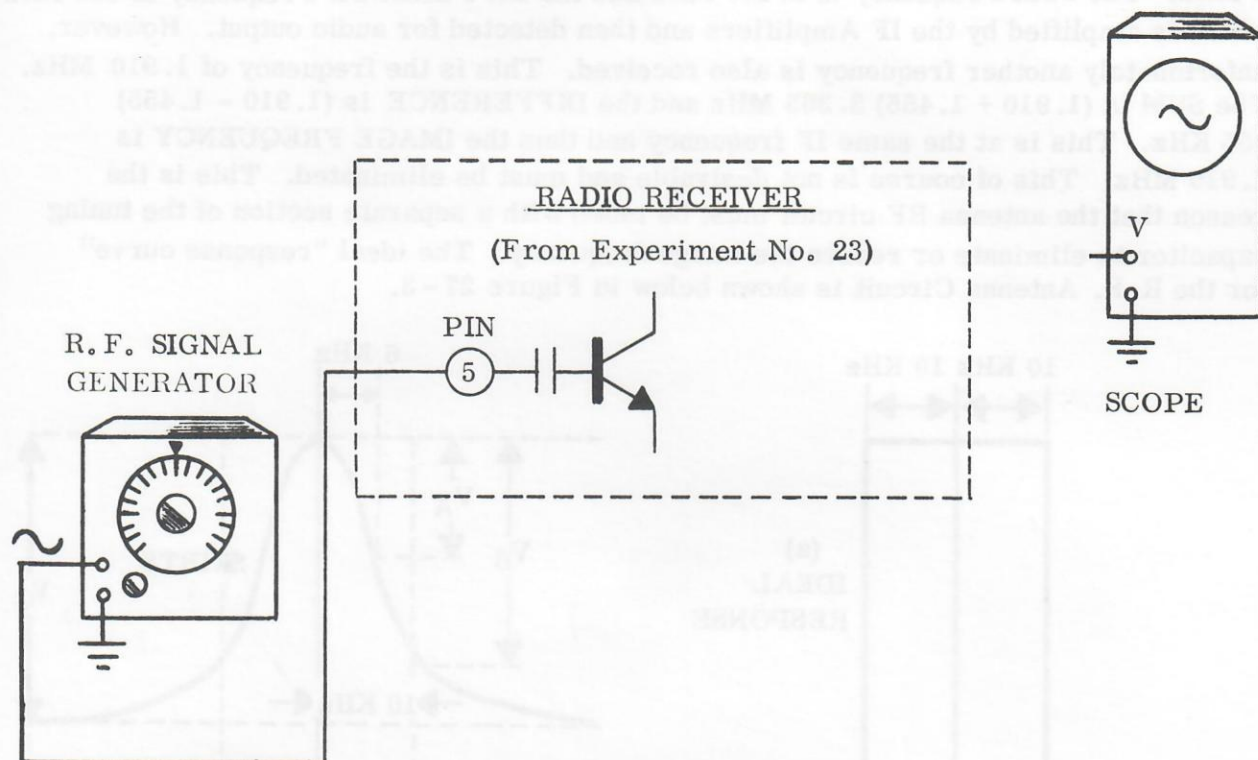


Figure 27 - 1 Image Frequency Measurement - EXPERIMENT

Objective:

You will review the concept of IMAGE FREQUENCIES and test the reception of this "false frequency" reception.

Description:

The Superhetrodyne Radio Mixes a Local Oscillator Frequency with an Input Radio Frequency which results in the IF Frequency of 455 KHz. A Block Diagram of the input to the Superhet Receiver is shown below:

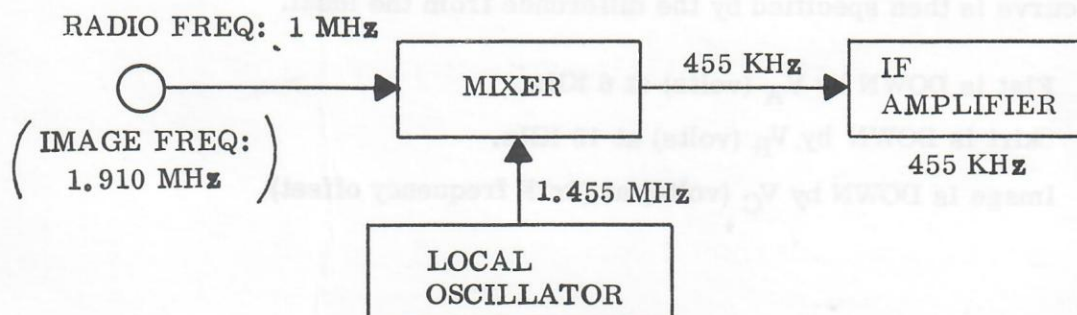


Figure 27 - 2 Mixer Frequencies

The Local Oscillator is set at 1.455 MHz to receive the Radio Station at 1 MHz. The SUM Frequency is 2.455 MHz and the DIFFERENCE Frequency is 455 KHz which is amplified by the IF Amplifiers and then detected for audio output. However, unfortunately another frequency is also received. This is the frequency of 1.910 MHz. The SUM is $(1.910 + 1.455)$ 3.365 MHz and the DIFFERENCE is $(1.910 - 1.455)$ 455 KHz. This is at the same IF frequency and thus the IMAGE FREQUENCY is 1.910 MHz. This of course is not desirable and must be eliminated. This is the reason that the antenna RF circuit must be tuned with a separate section of the tuning capacitor to eliminate or reduce the image frequency. The ideal "response curve" for the R.F. Antenna Circuit is shown below in Figure 27 - 3.

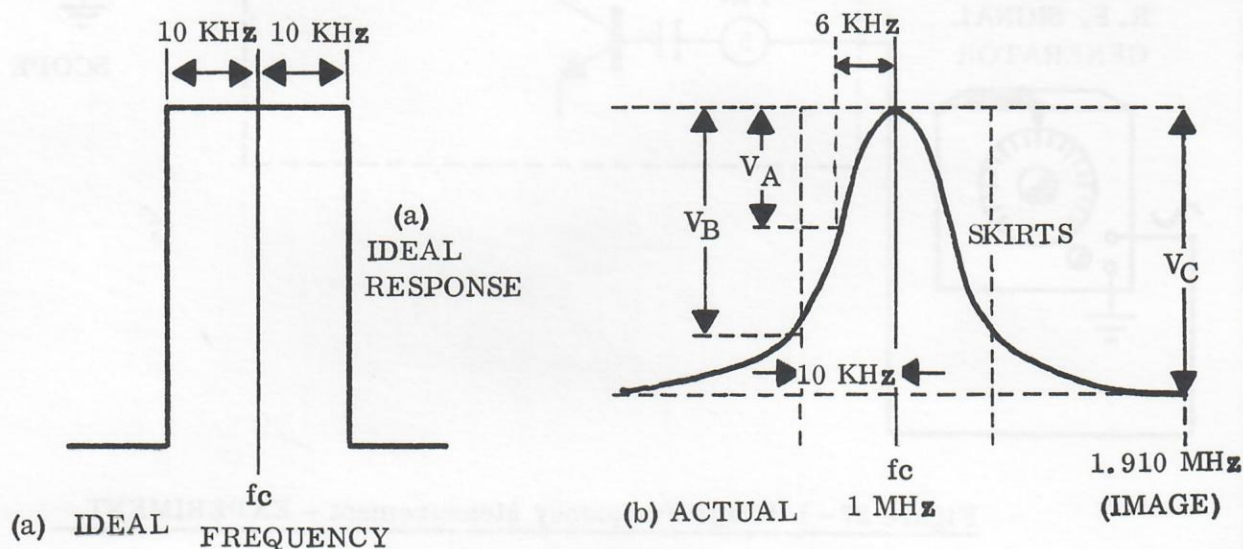


Figure 27 - 3 Selectivity

Referring to Figure 27 - 3 (a), all of the frequencies in the "band" are transmitted (flat top) and all of the frequencies outside of this band are eliminated. This is only the "ideal" response. The actual "response" or "selection" curve is shown in Figure 28 - 3(b). The top is not flat, and the ends or "skirts" are not sharp. The shape of this curve is then specified by the difference from the ideal.

Flat is DOWN by V_A (volts) at 6 KHz.

Skirt is DOWN by V_B (volts) at 10 KHz.

Image is DOWN by V_C (volts) at (2xIF frequency offset).

The voltages are measured in DECIBELS (described in another experiments) and a typical specification for SELECTIVITY is:

Selectivity: 6 Decibels at 6 KHz.
 25 Decibels at 10 KHz.

Image Rejection: 50 Decibels

Procedure:

1. Wire the entire AM Radio Receiver from Experiment No. 23
2. Connect the RF Signal Generator output to the Mixer input which is at the P.C. Connector Pin No. 5.
3. Set the R.F. Signal Generator Frequency at 1 MHz, with internal audio modulation.
4. Tune the Radio Receiver to this "1MHz station" using the Tuning Capacitor, at approximately mid position. You will hear the audio tone. (You may use the Oscilloscope if a Receiver is not available.)
5. Now increase the R.F. Signal Generator Frequency until the tone is heard again. Enter this RF Frequency, as read from the Signal Generator.

FIRST IMAGE FREQUENCY =

6. How does this image frequency compare with the anticipated frequency of 1.910 MHz?

The voltages are measured in DECIBELS (described in another experiment) and a typical specification for SELECTIVITY is:

Selectivity: 5 Decibels at 5 KHz.
22.5 Decibels at 10 KHz.

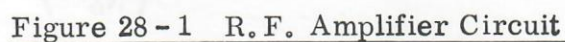
Image Rejection: 50 Decibels

Procedure:

1. Wire the radio AM Radio Receiver from Experiment No. 20.
2. Connect the RF signal generator output to the Mixer input which is at the P.C. Connector Pin No. 2.
3. Set the R.F. signal generator frequency at 1 MHz, with 100% audio modulation.
4. Tune the Radio Receiver to this "1MHz station" using the Tuning Capacitor, at approximately mid position. You will hear the audio tone. (You may use the Oscilloscope if a Receiver is not available.)
5. Now increase the R.F. signal generator frequency until the tone is heard again. Note this RF frequency, as read from the signal generator.

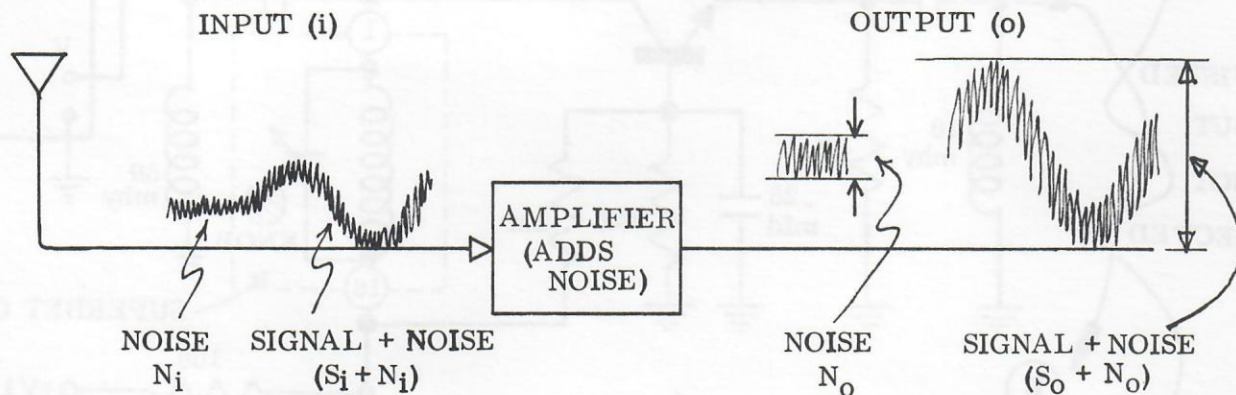
FIRST IMAGE FREQUENCY -

6. How does this image frequency compare with the anticipated frequency at 1.910 MHz?



The Mixer-Converter was the input circuit in the Superhetrodyne Radio Receivers in previous experiments. When it is desired to receive and detect weaker or more distant signals, an input amplifier is used for the radio frequency input directly. This RF Amplifier can be designed using a Vacuum Tube, or a FET (Field Effect Transistor), or a Transistor in a common-emitter amplifier circuit or in a common-base amplifier circuit. The RF input signals are very low and they are at high frequencies and it is desired that the amplifier respond to high frequencies and have low NOISE. Noise considerations are most important in low level signals, because as the signal is amplified, so is the noise. The noise generated

in the transistor in this input RF Amplifier is important in low signal level amplifiers, because the Amplifier Noise level may be close to the signal noise level. We specify a NOISE FACTOR to rate the quality of the input amplifier. Consider the diagram below:



SIGNAL - to - NOISE RATIO

$$\text{INPUT} = \frac{(S_i + N_i)}{N_i}$$

$$\text{OUTPUT} = \frac{(S_o + N_o)}{N_o}$$

$$\text{NOISE FACTOR} = \text{NF} = \frac{\left(\frac{S_i + N_i}{N_i} \right)}{\left(\frac{S_o + N_o}{N_o} \right)}$$

Consider the following readings for an amplifier with an approximate gain of 4.

$$(S_i + N_i) = 8 \text{ volts}$$

$$(N_i) = 2 \text{ volts}$$

$$(S_o + N_o) = 34 \text{ volts}$$

$$(N_o) = 10 \text{ volts}$$

The Noise Factor is given by

$$\left(\frac{S}{N} \right)_{\text{INPUT}} = \frac{8}{2} = 4$$

$$\left(\frac{S}{N} \right)_{\text{OUTPUT}} = \frac{34}{10} = 3.4 \quad (\text{Lower or Poorer})$$

$$\text{NOISE FACTOR} = \text{NF} = \frac{4}{3.4} = 1.2 \quad (\text{Voltage Ratio})$$

This is usually given in DECIBELS and is $\text{DB} = 20 \log \text{NF (in volts)}$

$$\text{NOISE FACTOR} = 1.2 \text{ (VOLTAGE RATIO)} = 1.5 \text{ DECIBELS}$$

The RF Amplifier Circuit is shown in Figure 28 - 1 uses a Common Base Transistor Amplifier. This is a very common circuit in RF Amplifiers because of good high frequency response and low input impedance to match the antenna input. The RF Amplifiers can be "wide-band" to cover the entire radio band, or can be a "Tuned RF Amplifier" to cover the frequency desired and thus provide lower noise because only noise at the tuned frequency bandwidth is amplified. Figure 28 - 1 shows a tuned RF Amplifier with a tuned coil in the collector or load circuit. You will measure the output Signal and Noise Levels. It is noted that in measuring low level signals, the measuring test instruments can introduce noise of their own and provide inaccurate readings. We will rely on the oscilloscope for our measurements.

The input is not connected directly, but the amplifier input wire (antenna) receives the signal from the RF Generator wire (transmitting antenna).

Procedure:

1. Wire the RF Amplifier Circuit in Figure 28 - 1. Use the Plug-in SUPERHET CARD.
2. Twist the amplifier input "wire" and the RF Generator "wire" together 5 turns to "couple" the RF Signal to the Amplifier.
3. Observe the Amplifier Output Signal (Switch A DOWN. Set the variable capacitor HALF-WAY closed. Set the RF Signal Generator voltage output at maximum, and adjust the RF Signal Generator frequency for a maximum output, which is at the tuned-frequency of the amplifier. (Between 500 KHz and 1.6 MHZ).
4. Record the output Signal + Noise and Noise Levels. Set the RF input level to zero to measure only noise. Enter the data below:

OUTPUT	(Signal + Noise)	=	volts	← peak-to-peak
	(Noise)	=	volts	← peak-to-peak

5. Calculate the Output Signal to Noise Ratio:

$$\text{Ratio} = \frac{(\text{Signal} + \text{Noise})}{\text{Noise}} = \underline{\hspace{2cm}}$$

OUTPUT	$\frac{(S+N)}{N}$	=
--------	-------------------	---

6. Observe the corresponding INPUT RF Signal (Switch A UP). Measure the Input Signal Level:

INPUT Signal (S+N) =

7. Calculate the RF Amplifier Gain (G):

$$G = \frac{\text{OUTPUT (S+N)}}{\text{INPUT (S+N)}} =$$

G =

8. The Sensitivity of a Radio is the ability to pickup or receive low-level input radio signals at the antenna and have them amplified without much noise or with a good or high Signal-to-Noise Ratio. The Specification for Radio Sensitivity is thus given as an input antenna voltage with a corresponding good Signal-to-Noise Ratio. A typical Sensitivity Specification would be as given below:

SENSITIVITY: 1 microvolt input for 10 DB of $\frac{(S+N)}{N}$

9. When measuring the input Signal + Noise the tuning capacitor on the Superhet Card may have to be adjusted for peak input voltage. Care must be taken that the signals measured are actually the signal generator output and not oscillation of the amplifier. This can be tested by changing the R.F. Generator amplitude and noting that the amplitude of the signal being measured varies correspondingly.

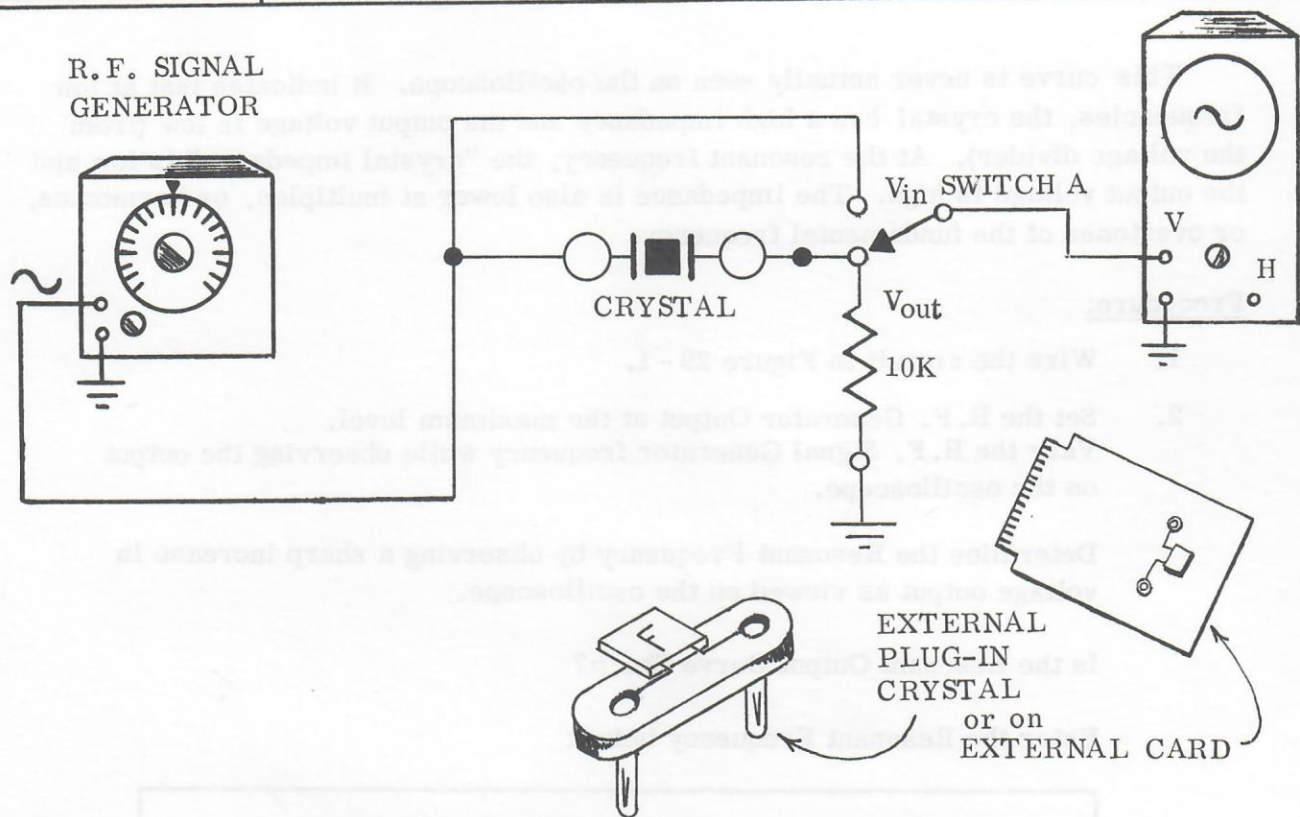


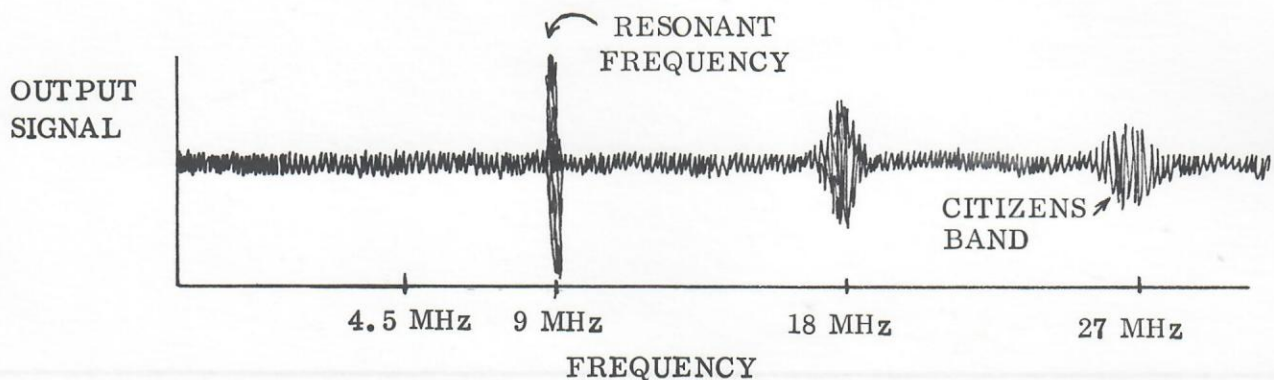
Figure 29 - 1 Crystal Filter Circuit - EXPERIMENT

Objective:

You will measure the Resonant Frequency of a CRYSTAL and observe that the Crystal behaves liked a tuned resonant circuit.

Description:

A crystal is mechanically cut as a thin crystal structure which exhibits the same properties as a series inductance-capacitance resonant circuit. There is a resonant frequency which results in a Low Impedance. The resonance is very sharp, corresponding to a very high "Q" circuit. There are also resonances at multiples of this frequency or at "overtones". The crystal used has approximately a 9 Megahertz resonant frequency. The resultant output as a function of frequency should appear as shown below:



This curve is never actually seen on the oscilloscope. It indicates that at low frequencies, the crystal has a high impedance and the output voltage is low (from the voltage divider). At the resonant frequency, the "crystal impedance" is low and the output voltage is high. The impedance is also lower at multiples, or harmonics, or overtones of the fundamental frequency.

Procedure:

1. Wire the circuit in Figure 29 - 1.
2. Set the R.F. Generator Output at the maximum level. Vary the R.F. Signal Generator frequency while observing the output on the oscilloscope.

Determine the Resonant Frequency by observing a sharp increase in voltage output as viewed on the oscilloscope.

Is the Resonant Output Curve Sharp?

Enter the Resonant Frequency below:

CRYSTAL RESONANT FREQUENCY =

The crystal acts as a very sharp Filter Circuit Component.

3. Increase the frequency higher than resonance and observe increased outputs at two times and three times the fundamental resonant frequency. The second harmonic will occur at a frequency of approximately 18 MHz and the third harmonic will occur at a frequency of approximately 27 MHz. The 18 MHz and 27 MHz frequencies are high and your Oscilloscope and R.F. Generator might not be capable of displaying or generating a good signal at these frequencies. Therefore, the 2nd and 3rd harmonics may not be easily found. The fundamental frequency of approximately 9 MHz should be easily measured and is the important measurement in this experiment.

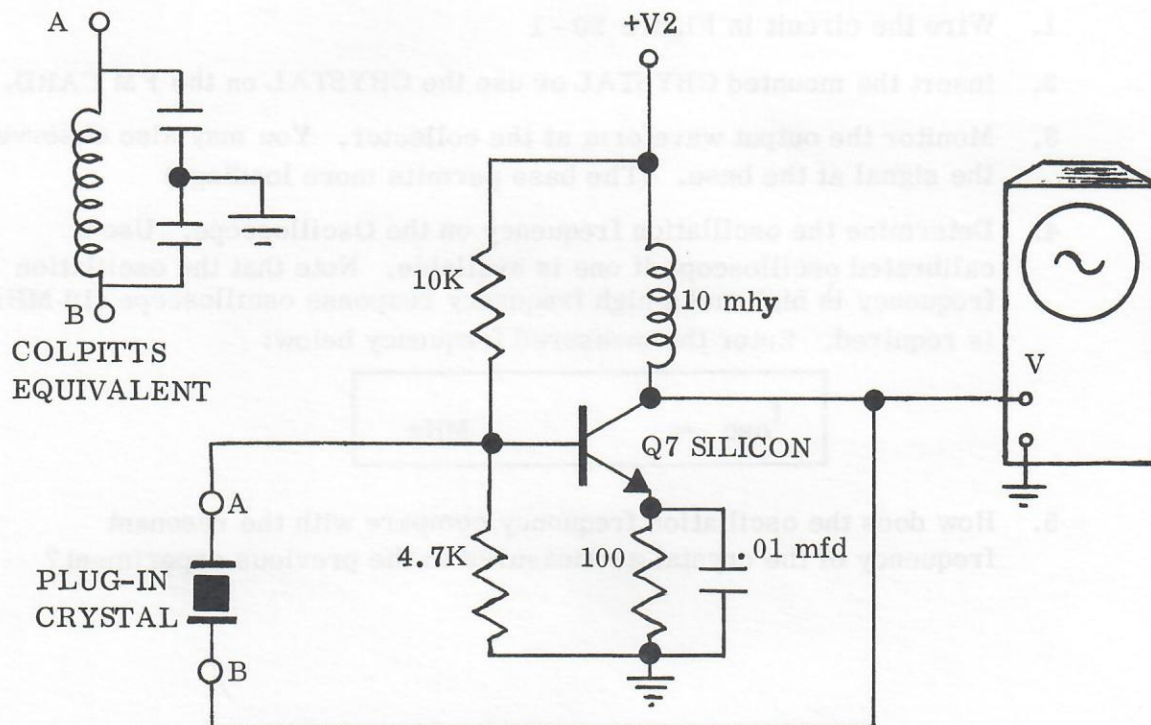


Figure 30 - 1 Pierce Crystal Oscillator - EXPERIMENT

Objective:

You will replace the parallel Inductor and Capacitors in the Colpitts Oscillator with a CRYSTAL. This results in a crystal oscillator called the Pierce Oscillator.

Description:

The circuit above is similar to the Colpitts Oscillator if the Crystal were replaced by the L-C circuit shown in the above sketch between the points marked A and B. The circuit oscillates at the Resonant Frequency of the Crystal.

Procedure:

1. Wire the circuit in Figure 30 - 1
2. Insert the mounted CRYSTAL or use the CRYSTAL on the FM CARD.
3. Monitor the output waveform at the collector. You may also observe the signal at the base. (The base permits more loading.)
4. Determine the oscillation frequency on the Oscilloscope. Use a calibrated oscilloscope if one is available. Note that the oscillation frequency is high and a high frequency response oscilloscope (10 MHz) is required. Enter the measured frequency below:

f_{osc}	=		MHz
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5. How does the oscillation frequency compare with the resonant frequency of the crystal as measured in the previous experiment?

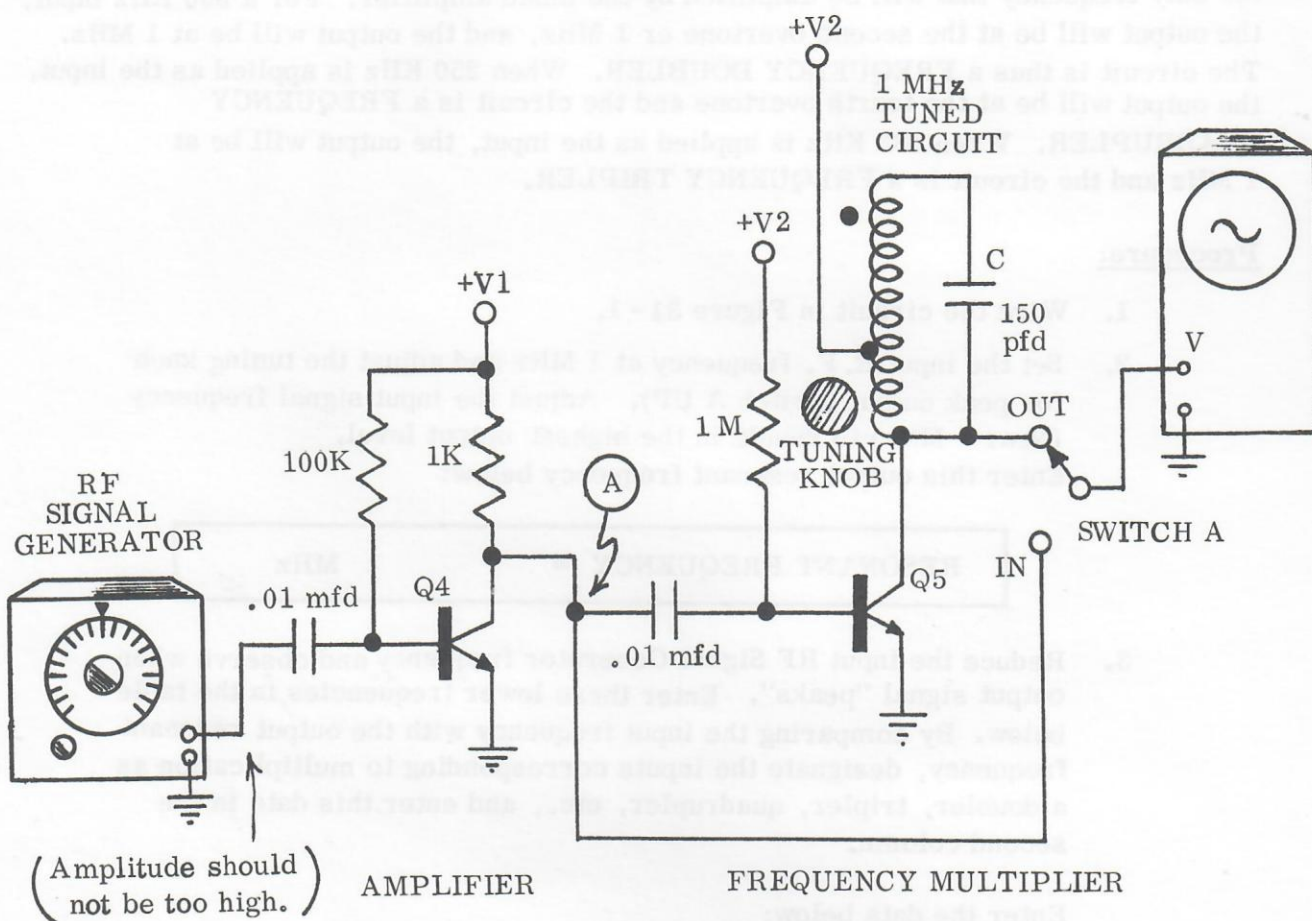


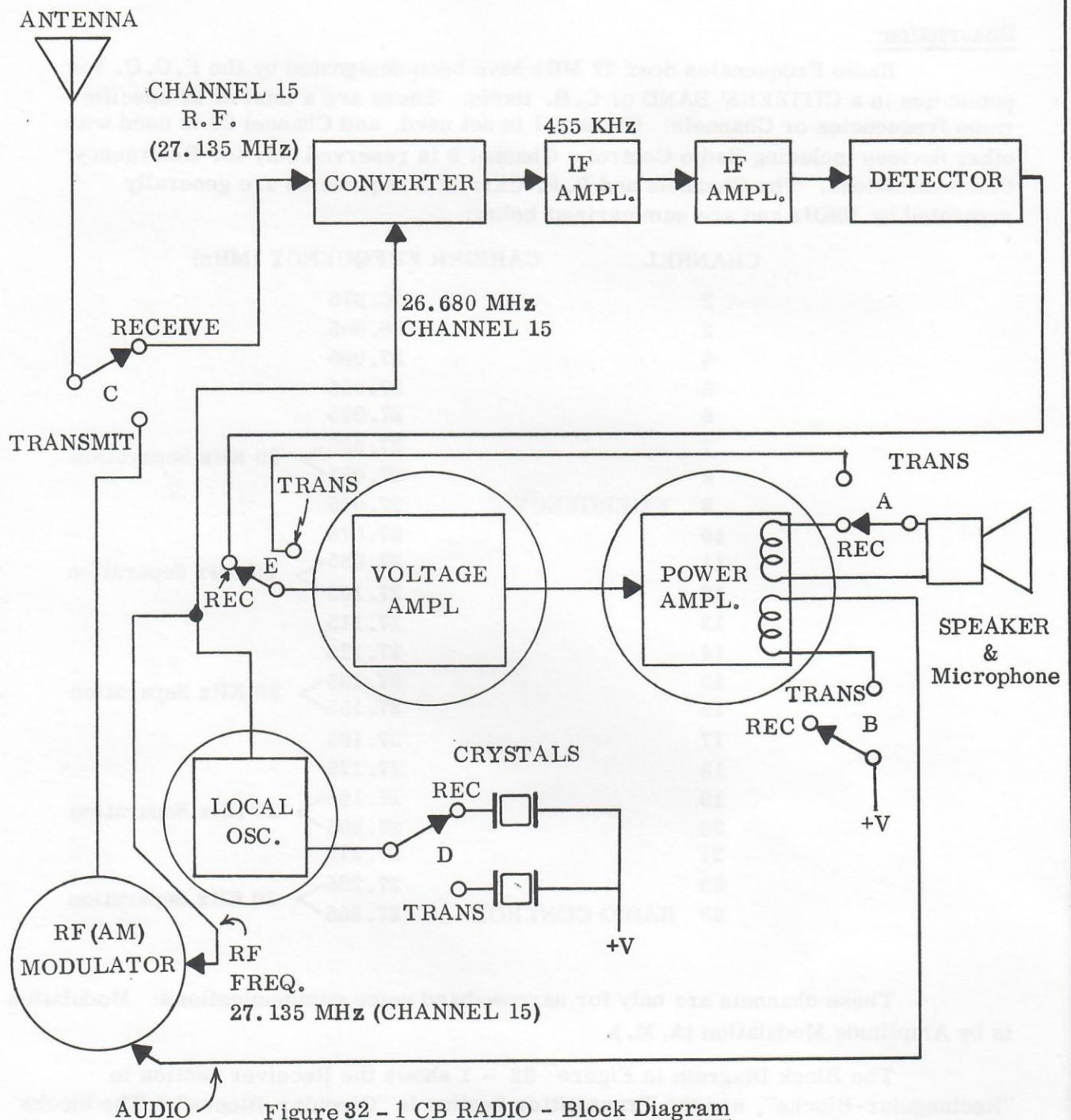
Figure 31 - 1 Frequency Multiplier Circuit

Objective:

You will drive a Tuned Amplifier with different frequencies and observe that the amplifier performs the function of a Frequency Multiplier.

Description:

The transistor Q4 Amplifier is an amplifier for the input signal. The transistor Q5 Amplifier has an L-C Tuned-Circuit collector load. This provides a high impedance and a high gain only at the tuned frequency which will be set at 1 MHz. When the input (A) is at any lower frequency such as 500 KHz, the waveform contains "harmonics" or "overtones" at twice, three times, four times, and so on, frequencies. The second harmonic component is at 1 MHz and this is

Objective:

You will review the concept of the Citizens' Band Radio Transmitter and Receiver or TRANSCEIVER. You will build and test a CB Transmitter using a Crystal Oscillator.

Description:

Radio Frequencies near 27 MHz have been designated by the F.C.C. for public use in a CITIZENS' BAND or C.B. Radio. There are a total of 23 specific radio frequencies or Channels. Channel 1 is not used, and Channel 23 is used with other devices including Radio Control. Channel 9 is reserved only for Emergency Communications. The Channels and R.F. Carrier Frequencies are generally separated by 10KHz and are summarized below:

CHANNEL	CARRIER FREQUENCY (MHz)	
2	26.975	
3	26.985	
4	27.005	
5	27.015	
6	27.025	
7	27.035	> 20 KHz Separation
8	27.055	
9 EMERGENCY	27.065	
10	27.075	
11	27.085	> 20 KHz Separation
12	27.105	
13	27.115	
14	27.125	
15	27.135	> 20 KHz Separation
16	27.155	
17	27.165	
18	27.175	
19	27.185	> 20 KHz Separation
20	27.205	
21	27.215	
22	27.225	> 20 KHz Separation
23 RADIO CONTROL	27.255	

These channels are only for narrow-band voice communications. Modulation is by Amplitude Modulation (A. M.).

The Block Diagram in Figure 32 - 1 shows the Receiver Section in "Rectangular-Blocks", and the Transmitter Section in "Circular-Blocks". The blocks of LOCAL OSCILLATOR, AUDIO AMPLIFIER & POWER AMPLIFIER are used in both the Transmitter & Receiver. The C.B. Receiver is the same as the Broadcast Band AM Receiver consisting of the LOCAL OSCILLATOR, CONVERTER, IF AMPIIFIERS, DETECTOR, AUDIO AMPLIFIER, & POWER AMPLIFIER. The Local Oscillator is set at 455 KHz below the Radio Frequency for a 455 KHz I.F. Frequency. In order to

accurately control and easily tune each channel, a Crystal Oscillator is usually used in the receiver Local Oscillator Circuit. Thus, for Channel 15, the R. F. Frequency is 27.135 MHz, and the Local Oscillator is 26.680 MHz (27.135 MHz-455 KHz). The three Switches in the diagram are shown in the RECEIVE mode.

The Transmitter Block is shown in the Circles. When transmitting, the Switches are connected to the TRANS or Transmit Mode. The Speaker becomes the Microphone and is connected to the AUDIO AMPLIFIER (Switch A). The POWER AMPLIFIER is connected to an output RF MODULATOR via Switch (B) which connects Power to an additional winding on the Output Amplifier, which is in turn connected to the RF MODULATOR, providing Power in a "Collector-Modulation" circuit. Switch C connects the ANTENNA to the RF MODULATOR OUTPUT and disconnects the Converter. Switch D disconnects the Receiver Crystal (which was tuned at 455 KHz below the RF Frequency) to the correct RF Transmission frequency (27.135 MHz for Channel 15). A crystal must be used for transmitting because it is necessary to accurately control the transmission frequency.

Figure 32 - 2 shows a complete CB Transceiver circuit schematic. Observe the similarity between the circuits that you have studied and the CB Transceiver circuit.

Typical CB Transceiver specifications for these circuits are:

Frequency Range	26.975 to 27.255 MHz (Channels 2-23)
Transmitter	(a) 100 milliwatts input to final RF Amplifier. (FCC Regulation part 15, no license) or (b) 5 watts input to final RF Amplifier. (FCC Regulation, License required)
Modulation	Over 95%
Sensitivity	1 μ V. for 10 db $\frac{S+N}{N}$ (Described in Experiment 28.)
Selectivity	6KHz, less than 6 db (Described in 15KHz, more than 25 db Experiment 27.)
Audio Output Power	(a) 100 milliwatts or (b) 5 watts (License required)

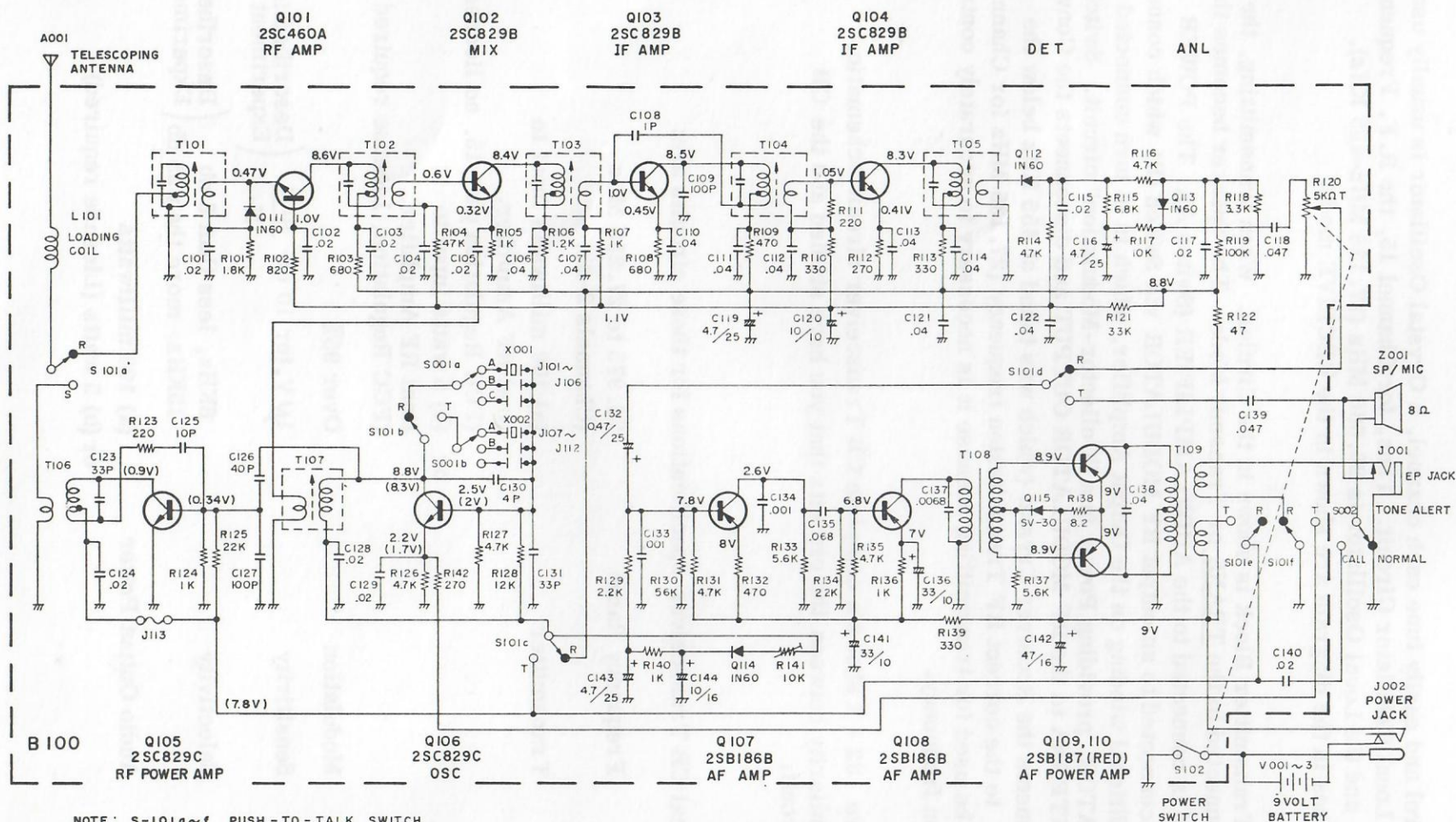


Figure 32-2 CB TRANSCEIVER

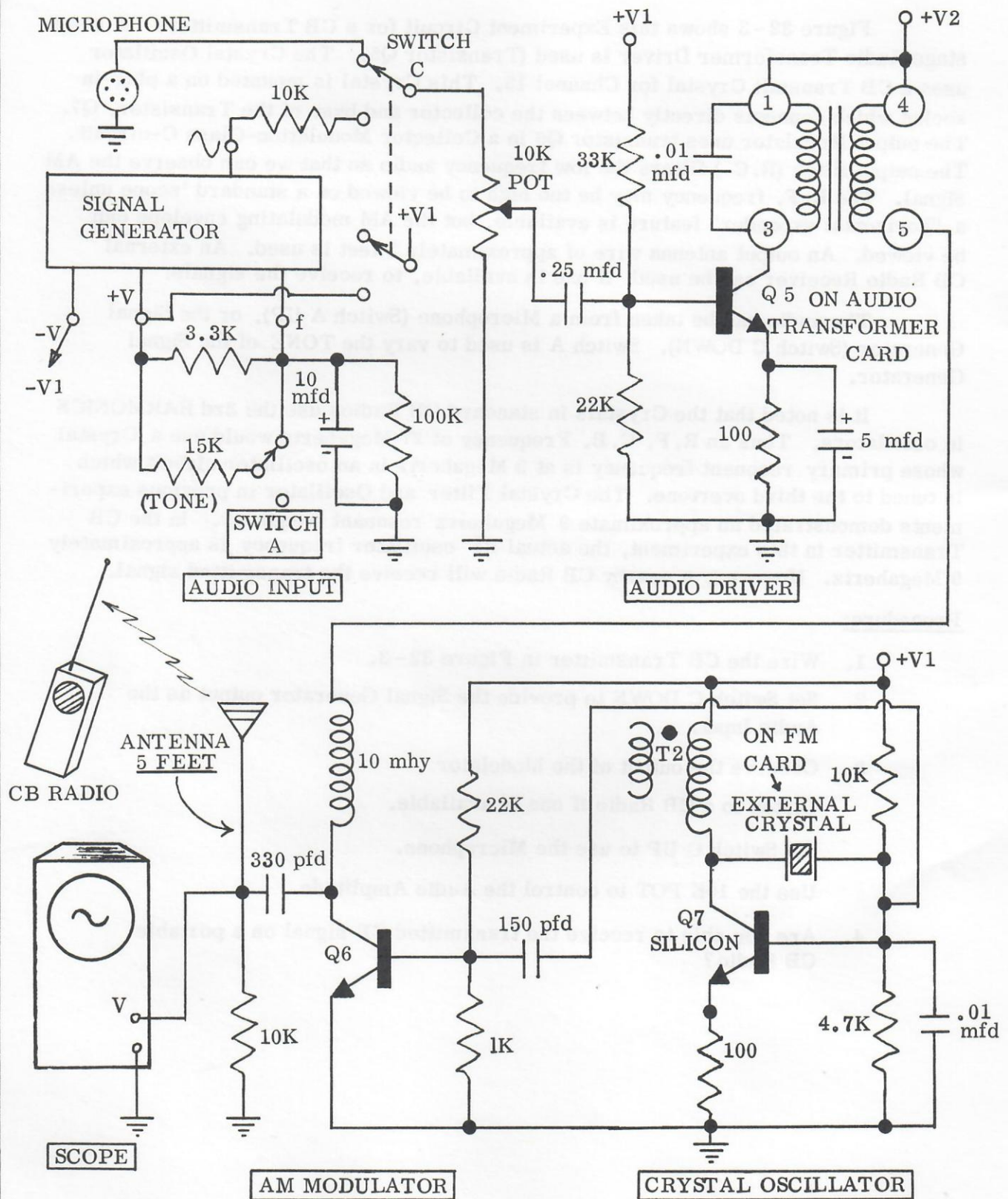


Figure 32 - 3 CB TRANSMITTER

Figure 32-3 shows this Experiment Circuit for a CB Transmitter. A single stage Audio Transformer Driver is used (Transistor Q5). The Crystal Oscillator uses a CB Transmit Crystal for Channel 15. This Crystal is mounted on a plug-in socket which connects directly between the collector and base of the Transistor, Q7. The output Modulator uses transistor Q6 in a Collector Modulation-Class C-circuit. The output filter (R.C.) filters the low frequency audio so that we can observe the AM Signal. The R.F. frequency may be too high to be viewed on a standard 'scope unless a "horizontal expander" feature is available, but the AM modulating envelope can be viewed. An output antenna wire of approximately 5 feet is used. An external CB Radio Receiver can be used, if one is available, to receive the signals.

The audio can be taken from a Microphone (Switch A UP), or the Signal Generator (Switch C DOWN). Switch A is used to vary the TONE of the Signal Generator.

It is noted that the Crystals in standard CB Radios use the 3rd HARMONICS in oscillators. Thus an R.F. C.B. Frequency of 27 Megahertz would use a Crystal whose primary resonant frequency is at 9 Megahertz in an oscillator circuit which is tuned to the third overtone. The Crystal Filter and Oscillator in previous experiments demonstrated an approximate 9 Megahertz resonant frequency. In the CB Transmitter in this experiment, the actual RF oscillator frequency is approximately 9 Megahertz. However, a nearby CB Radio will receive the transmitted signal.

Procedure:

1. Wire the CB Transmitter in Figure 32-3.
2. Set Switch C DOWN to provide the Signal Generator output as the Audio Input.

Listen to a CB Radio if one is available.

Set Switch C UP to use the Microphone.

Use the 10K POT to control the Audio Amplitude.
3. Observe the output of the Modulator.
4. Are you able to receive the transmitted CB signal on a portable CB Radio?

PIN NUMBERS IN THIS DIAGRAM REFER TO THE PINS ON THE PLUG-IN FM CARD.

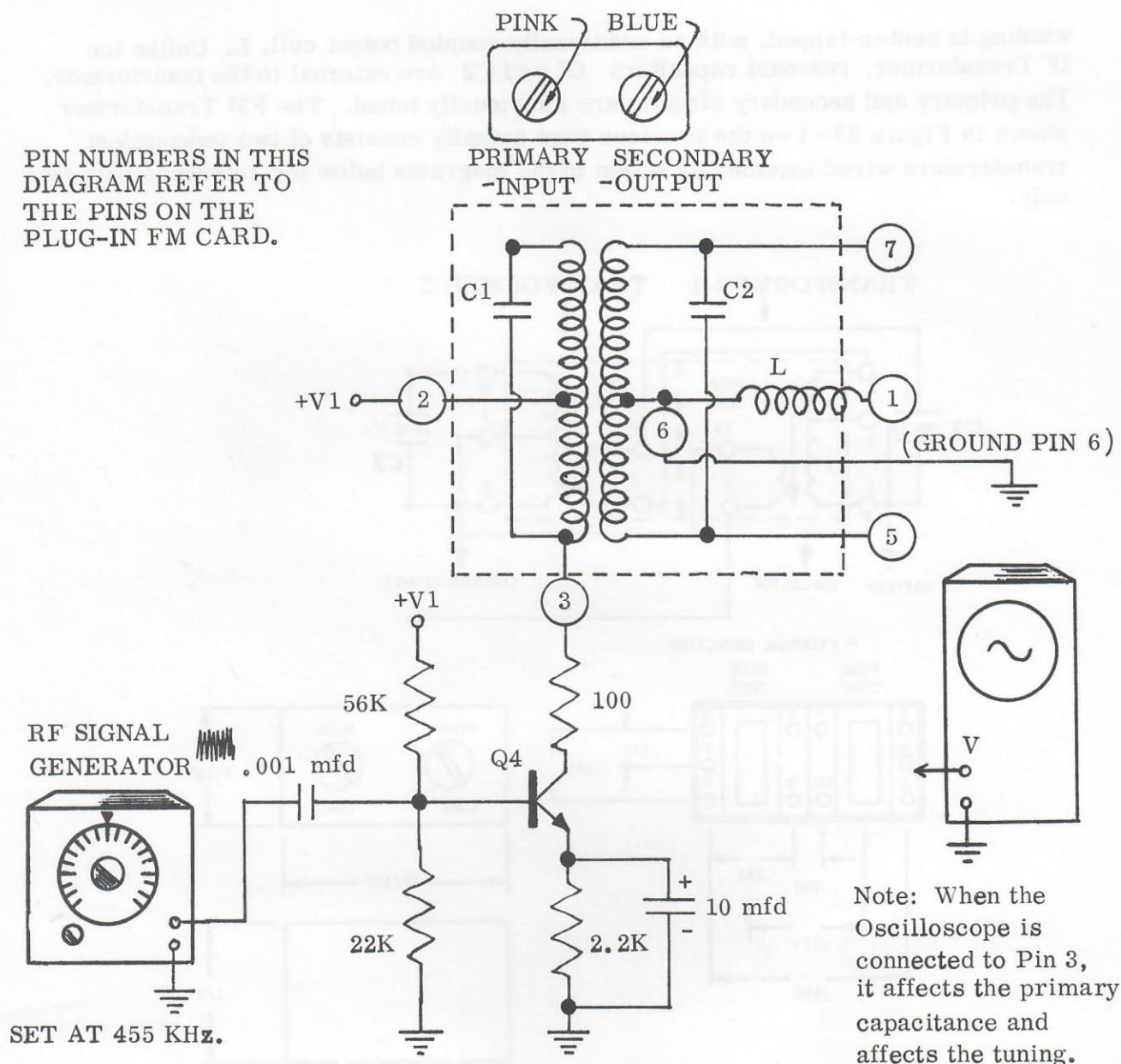


Figure 33-1 FM Demodulator Transformer

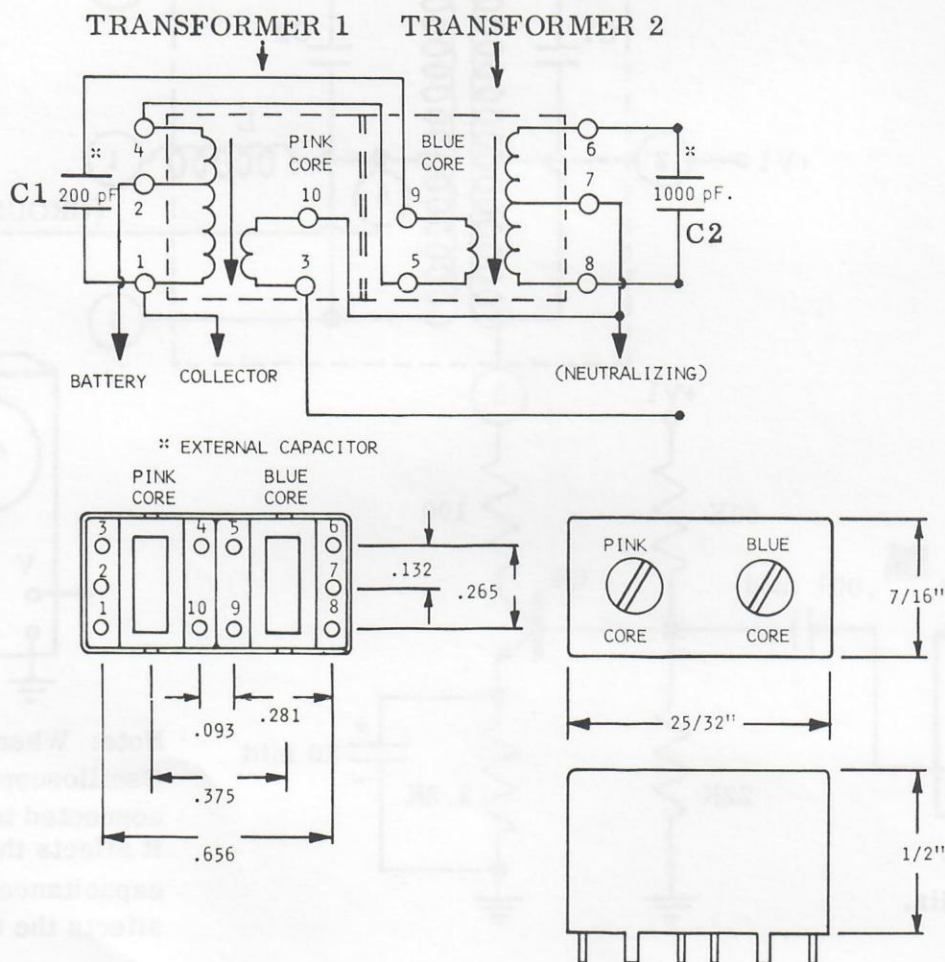
Objective:

You will test an FM Demodulator Transformer in an amplifier circuit, and you will tune both the primary and secondary circuit by adjusting the TUNING SLUGS.

Description:

The FM Transformer used in FM Demodulator or Detector circuits is similar in operation to the IF Transformers used in the previous superhetrodyne radio experiments. The primary input coil is used in a transistor collector circuit similar to the IF amplifier circuits and is shown in Figure 33-1. The secondary

winding is center-tapped, with an additionally coupled output coil, L. Unlike the IF Transformer, resonant capacitors C1 and C2 are external to the transformer. The primary and secondary circuits are individually tuned. The FM Transformer shown in Figure 33 - 1 on the previous page actually consists of two independent transformers wired together as shown in the diagrams below for reference purposes only.



FREQUENCY	FUNCTION	BANDWIDTH
455 kHz Zi=25K Zo=5K	RATIO DETECTOR	20 kHz PEAK TO PEAK

The primary coil tuning is achieved by the PINK tuning slug and the secondary or output coil tuning is achieved by the BLUE tuning coil. The two transformers are connected as shown in the diagram on the previous page to result in the equivalent of a single FM Transformer.

The FM Transformer is mounted on a printed-circuit plug-in card which is inserted into the Ed-Lab P.C. Socket. The two separate transformers, which are housed in a single can, are connected to result in the single transformer configuration. The two external capacitors, primary $C1 = 330$ pfd and secondary $C2 = .001$ mfd, are also mounted on the card.

This experiment is concerned with observing the primary and secondary voltages as the input frequency is varied and as the transformer tuning is adjusted. The Discriminator Transformer used in this experiment has an IF frequency which is the same as that of standard AM Radios, 455 KHz.

Procedure:

CAUTION: EXTREME CARE MUST BE TAKEN WHENEVER ATTEMPTING TO TUNE THE COIL. THE SLUGS ARE SOFT AND MAY BE RUINED BY USING SHARP TOOLS OR BY ATTEMPTING TO TURN THE SLUG PAST ITS NORMAL RANGE WHERE IT IS HARD TO TURN. WHEN YOU FEEL RESISTANCE TO TURNING -- STOP -- DON'T FORCE THE SLUG.

1. Wire the circuit in Figure 33 - 1.
2. Plug the FM CARD into the Ed-Lab 650 P.C. Socket.
3. Connect the oscilloscope lead to card Pin No. 3 to observe the amplifier signal.
4. Carefully adjust the PINK tuning slug until the output signal at Pin 3 is at maximum amplitude.

Record this amplitude

PIN (3)	Transformer Input =	PEAK to PEAK
---------	---------------------	--------------

5. Change the oscilloscope lead connection to Pin 7 which is the secondary winding of the FM Transformer. Carefully adjust the BLUE tuning slug for maximum output. Leave the oscilloscope connection at Pin 7 and now readjust the PINK core for maximum output at Pin 7. This readjustment is necessary because the oscilloscope loads on the transformer primary when the oscilloscope was connected to Pin 3. Record this secondary amplitude below:

PIN (7)	Transformer Output =	PEAK to PEAK
---------	----------------------	--------------

6. Is the transformer (Step-Up) or (Step-Down)? _____
7. Record the Signal Amplitude at the output from the Transformer (Pin 7) as the Signal Generator output is varied. Record the results in the table below:

FREQUENCY	TRANSFORMER OUTPUT
400 KHZ	
420 KHZ	
440 KHZ	
445 KHZ	
460 KHZ	
480 KHZ	
500 KHZ	

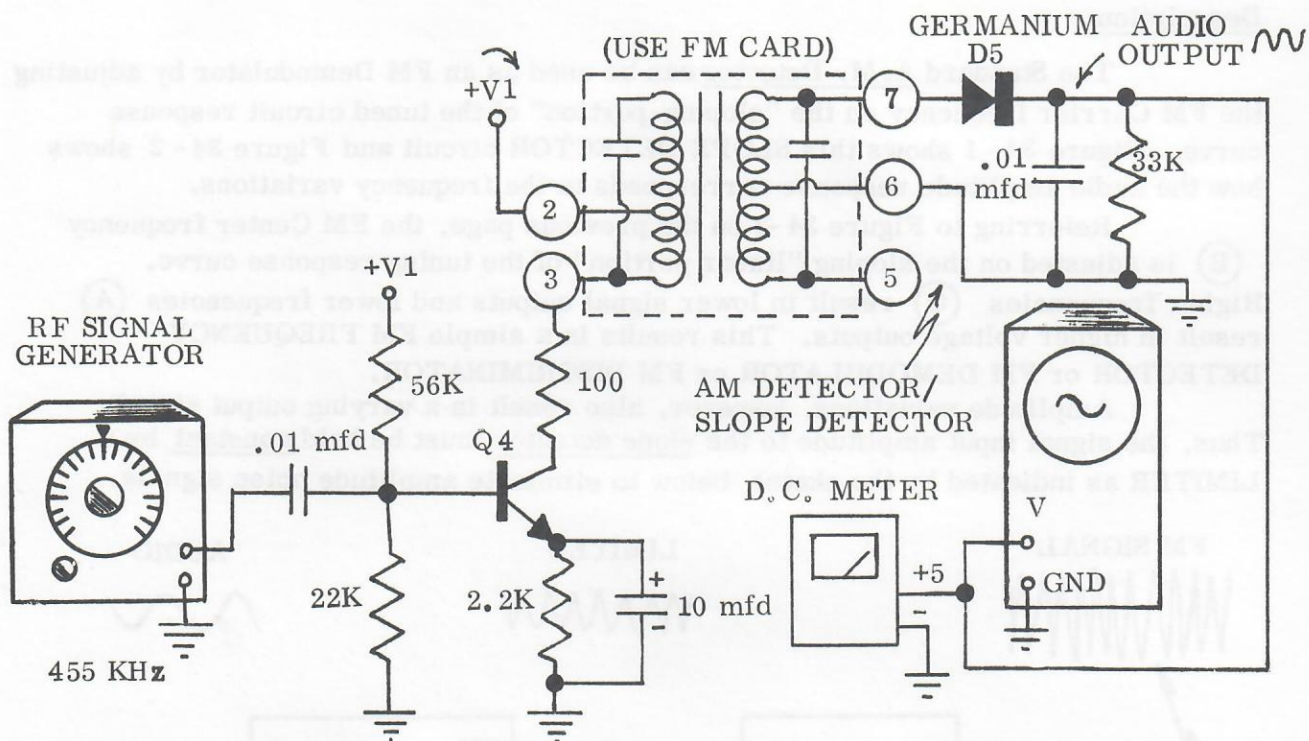


Figure 34 - 1 FM SLOPE DETECTOR - EXPERIMENT

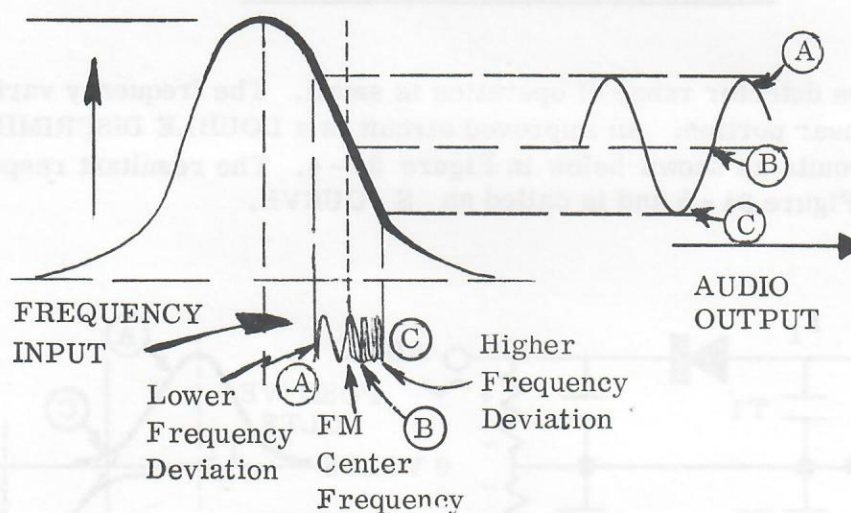


Figure 34 - 2 SLOPE AUDIO RESPONSE

Objective:

You will study FM Demodulators used to recover Audio Signals from frequency modulated carrier frequencies or intermediate frequencies. The circuits discussed include a Slope Detector, Foster-Seeley Discriminator and Ratio Detector. You will build and test the Slope Detector in this experiment.

Description:

The Standard A.M. Detector can be used as an FM Demodulator by adjusting the FM Carrier frequency on the "sloping-portion" of the tuned circuit response curve. Figure 34-1 shows this SLOPE DETECTOR circuit and Figure 34-2 shows how the audio amplitude response corresponds to the frequency variations.

Referring to Figure 34-2 on the previous page, the FM Center frequency (B) is adjusted on the sloping "linear portion" of the tuning response curve. Higher frequencies (C) result in lower signal outputs and lower frequencies (A) result in higher voltage outputs. This results in a simple FM FREQUENCY DETECTOR or FM DEMODULATOR or FM DISCRIMINATOR.

Amplitude variations, however, also result in a varying output signal. Thus, the signal input amplitude to the slope detector must be held constant by a LIMITER as indicated by the sketch below to eliminate amplitude noise signals.

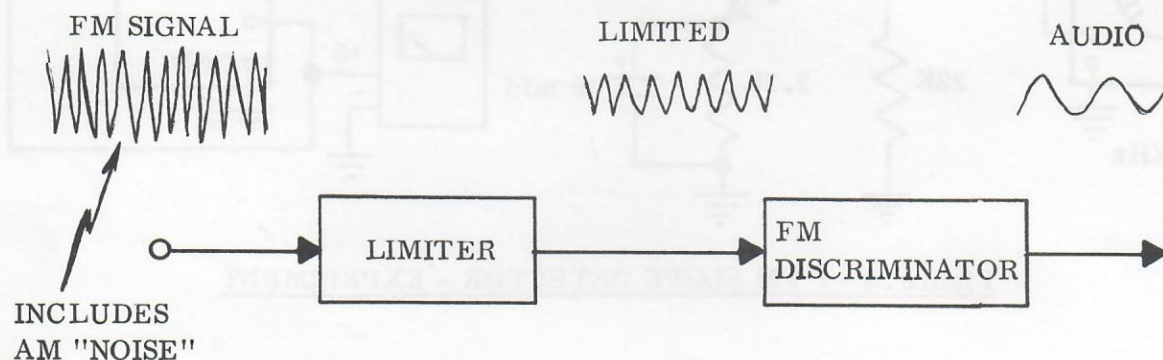


Figure 34-3 LIMITER OPERATION

The slope detector range of operation is small. The frequency variation is limited to the linear portion. An improved circuit is a DOUBLE DISCRIMINATOR using two tuned circuits as shown below in Figure 34-4. The resultant response curve is shown in Figure 34-5 and is called an S CURVE.

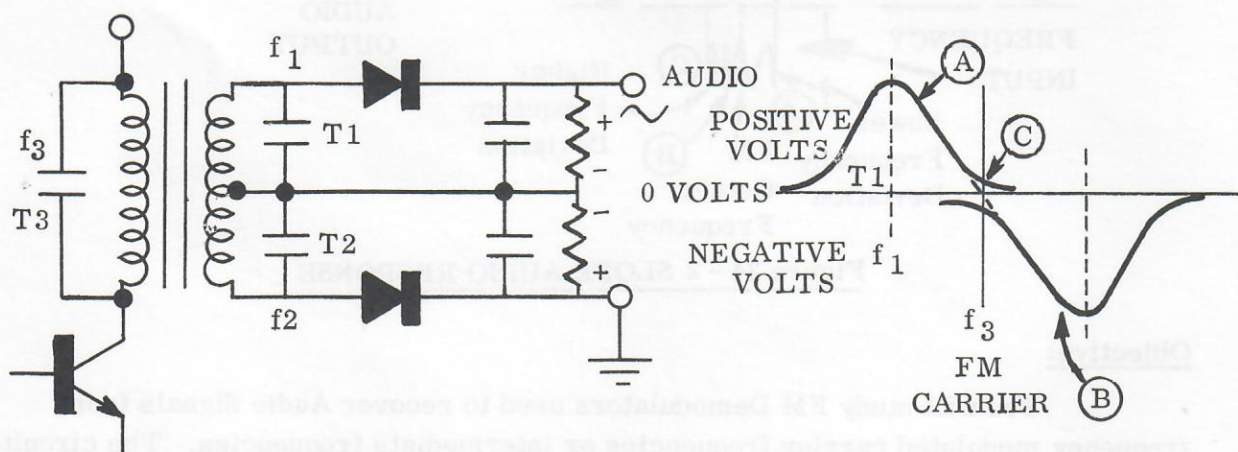


Figure 34-4 Double Tuned Discriminator

Figure 34-5 Response

Tuned circuit T1 is tuned at a lower frequency than the FM Carrier Frequency, and tuned circuit T2 is tuned higher than the carrier. The "linear portion" of the response curve is now twice as long, from (A) to (B), with high gain outputs for positive and negative frequency variations. This circuit is called a DOUBLE-TUNED DISCRIMINATOR because the two tuned circuits T1 and T2 are tuned to different frequencies, f_1 and f_2 . This circuit is sometimes called a TRIPLE-TUNED DISCRIMINATOR because the input circuit T3 (in Fig. 34-4) must be tuned to the middle of the f_1 and f_2 frequencies, that is at the carrier frequency, f_c . This circuit has the disadvantage that there are 3 circuits to tune which is difficult to adjust and expensive to manufacture.

An improved version of this circuit is the FOSTER-SEELY DISCRIMINATOR circuit shown below in Figure 34-5 which only requires tuning at the center frequency. This circuit is analyzed in many textbooks by the use of Vectors. The tuned transformer section in the collector is at resonance at the center or IF frequency. At higher frequencies it becomes Inductive and at lower frequencies it becomes Capacitive. The coupling capacitor C1 couples the AC voltage and phase at the collector to the center tap of the transformer. The phase of the current and voltages in the secondary (output) change with frequency resulting in changes in voltage output similar to the double tuned response. A LIMITER is still needed with the Foster-Seeley Discriminator.

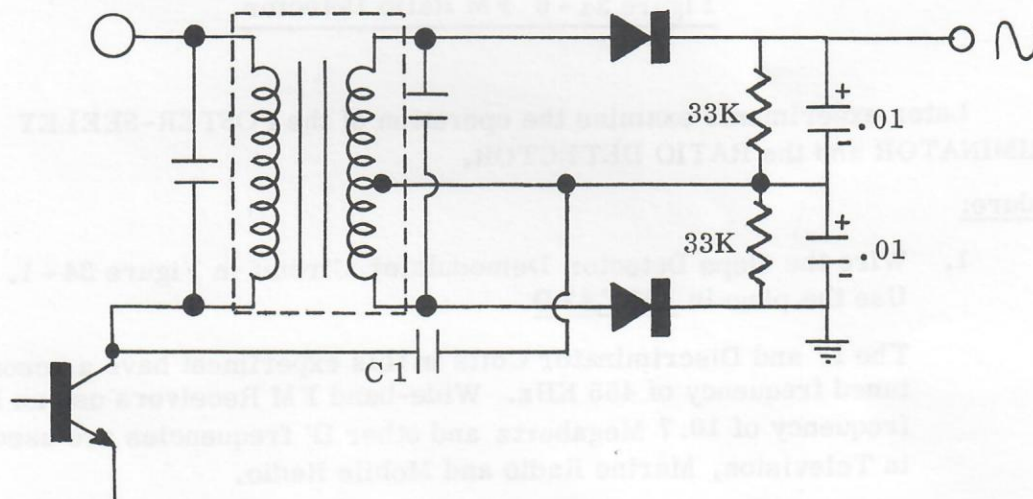


Figure 34 - 5 Foster - Seely Discriminator

Another variation of this circuit, which is not affected by amplitude variations and therefore does not need a Limiter, is the RATIO DETECTOR. In this circuit the diodes are reversed. The RF signal amplitude variations do not affect the audio output. Here again textbooks describe the operation of this circuit by the use of Vectors. The Ratio Detector is shown below in Figure 34-6.

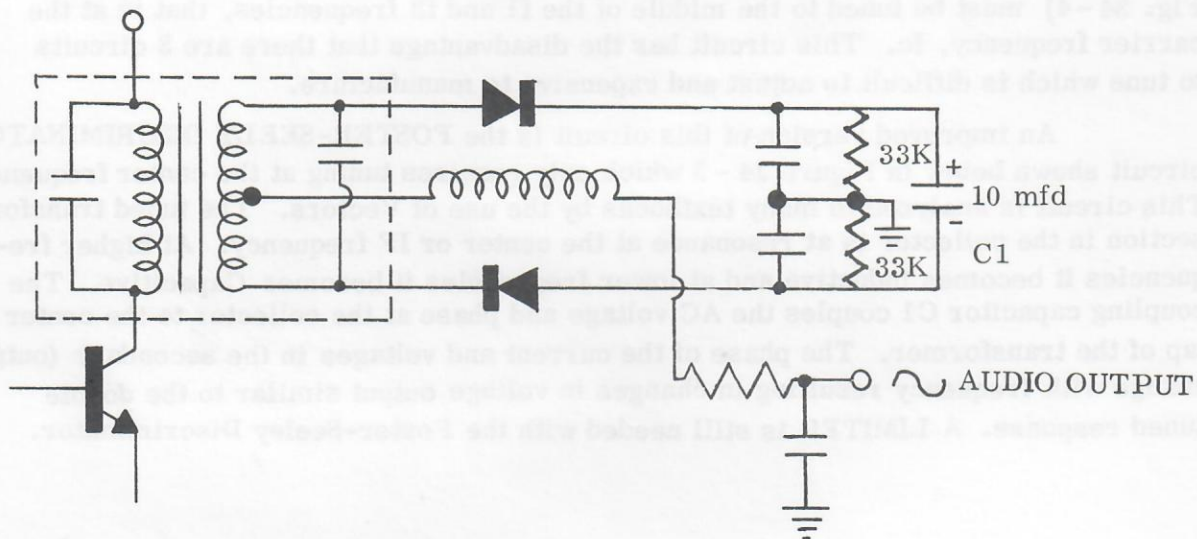


Figure 34 - 6 FM Ratio Detector

Later experiments examine the operation of the FOSTER-SEELEY DISCRIMINATOR and the RATIO DETECTOR.

Procedure:

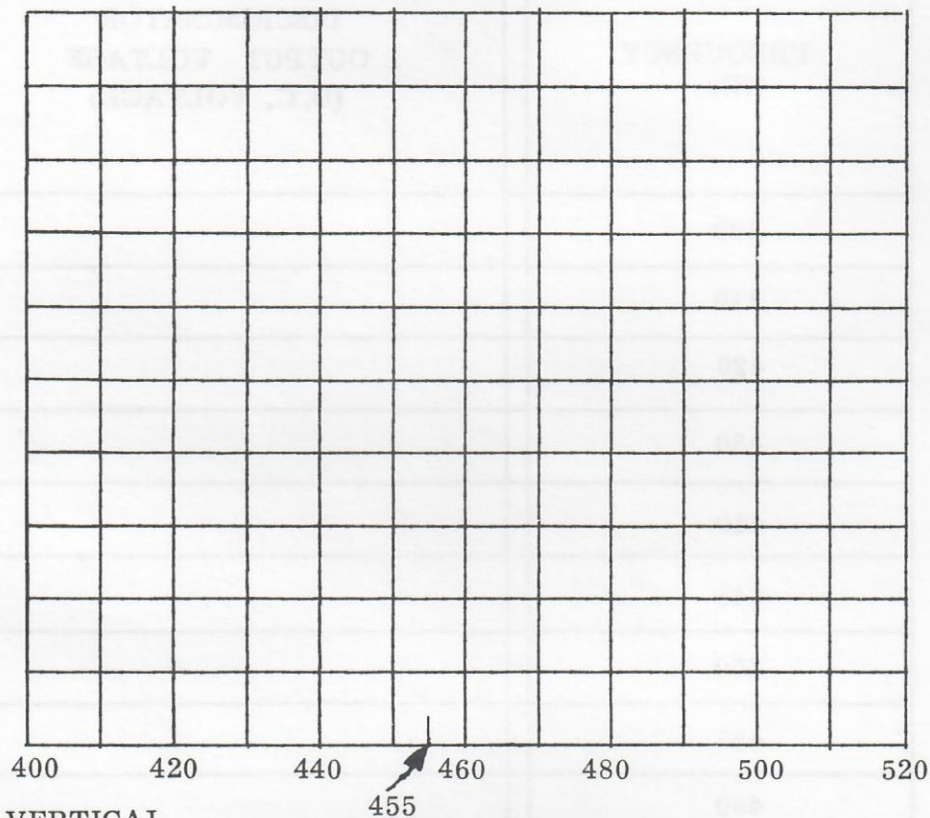
1. Wire the Slope Detector Demodulator Circuit in Figure 34 - 1. Use the plug-in FM CARD.

The IF and Discriminator Coils in this experiment have a resonant tuned frequency of 455 KHz. Wide-band FM Receivers use an IF frequency of 10.7 Megahertz and other IF frequencies are used in Television, Marine Radio and Mobile Radio.

2. Set the R.F. Signal Generator at 455 KHz and tune the F.M. transformer for maximum output voltage. Adjust the R.F. Signal Gen Generator Amplitude for a convenient voltage reading on the D.C. meter.
3. Set the R.F. Signal Generator at various frequency deviations above and below the center IF frequency of 455 KHz. Record the Slope Detector output voltages. Enter the data in the table on the following page.

FREQUENCY KHz	DISCRIMINATOR OUTPUT VOLTAGE (D.C. VOLTAGE)
400	
410	
420	
430	
440	
445	
450	
455	
460	
465	
470	
480	
490	
500	
510	

4. Plot the Audio or D.C. Voltage Outputs versus frequency below for the Slope Detector.



SELECT VERTICAL
SCALE MARKINGS
TO ACCOMMODATE
THE PEAK D.C.
METER READINGS

FREQUENCY KILOHERTZ
FM SLOPE DETECTOR RESPONSE

5. What is the useful frequency deviation (linear) range of this circuit as determined from the above graph?

FREQUENCY RANGE = _____ KHz to _____ KHz.

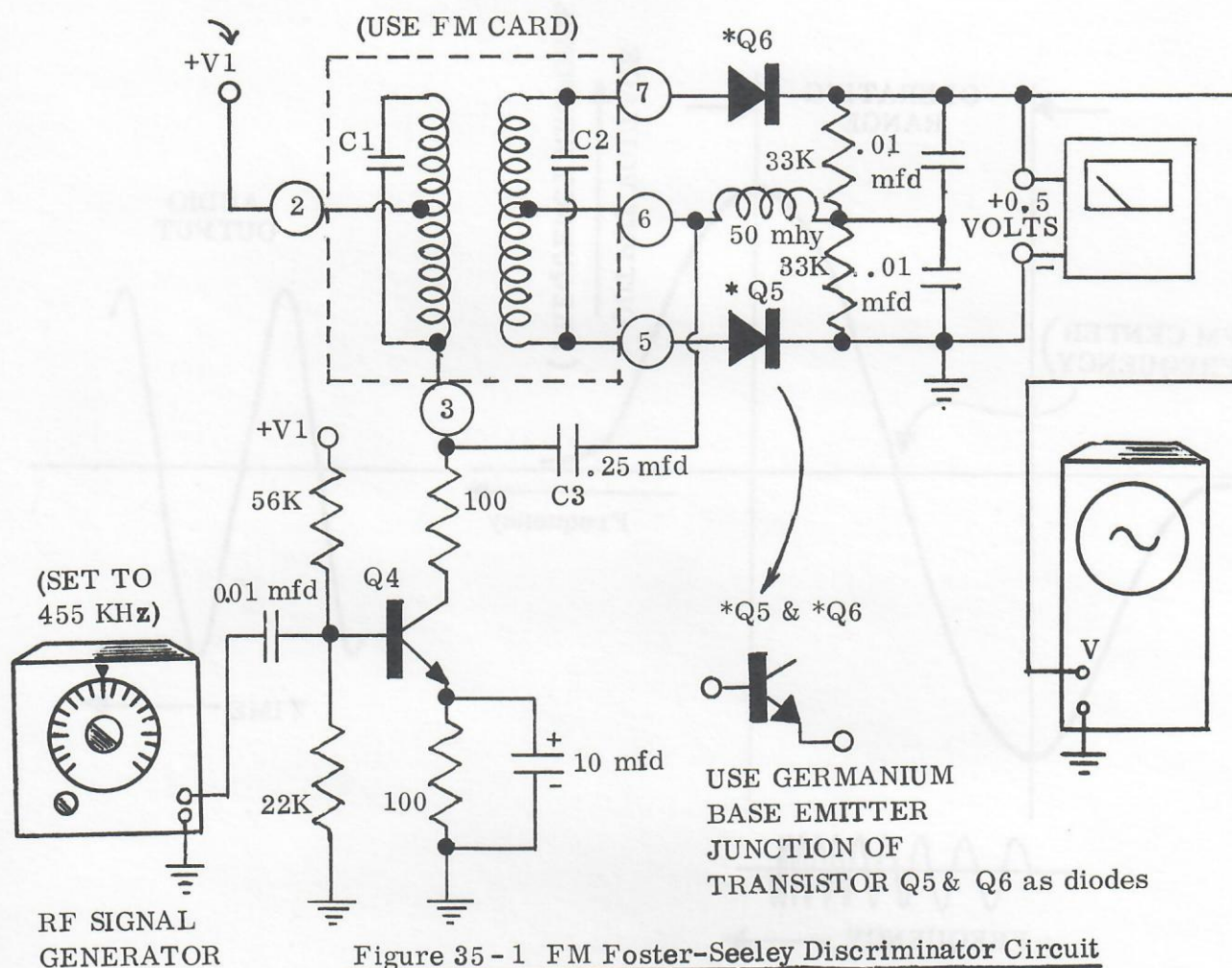


Figure 35 - 1 FM Foster-Seeley Discriminator Circuit

Objective:

You will build and test the FM Foster-Seeley Discriminator circuit and measure the output voltage level as the frequency is varied.

Description:

The basic FM Detector or Frequency Discriminator circuits were described in the previous experiment. The Foster-Seeley Discriminator is extremely useful because it provides a very wide range of frequency variation, where the smallest or null output audio signal level is at the resonant or center or carrier frequency. As the frequency deviates from the carrier frequency, the audio signal amplitude increases in the positive and negative directions as shown on the following page:

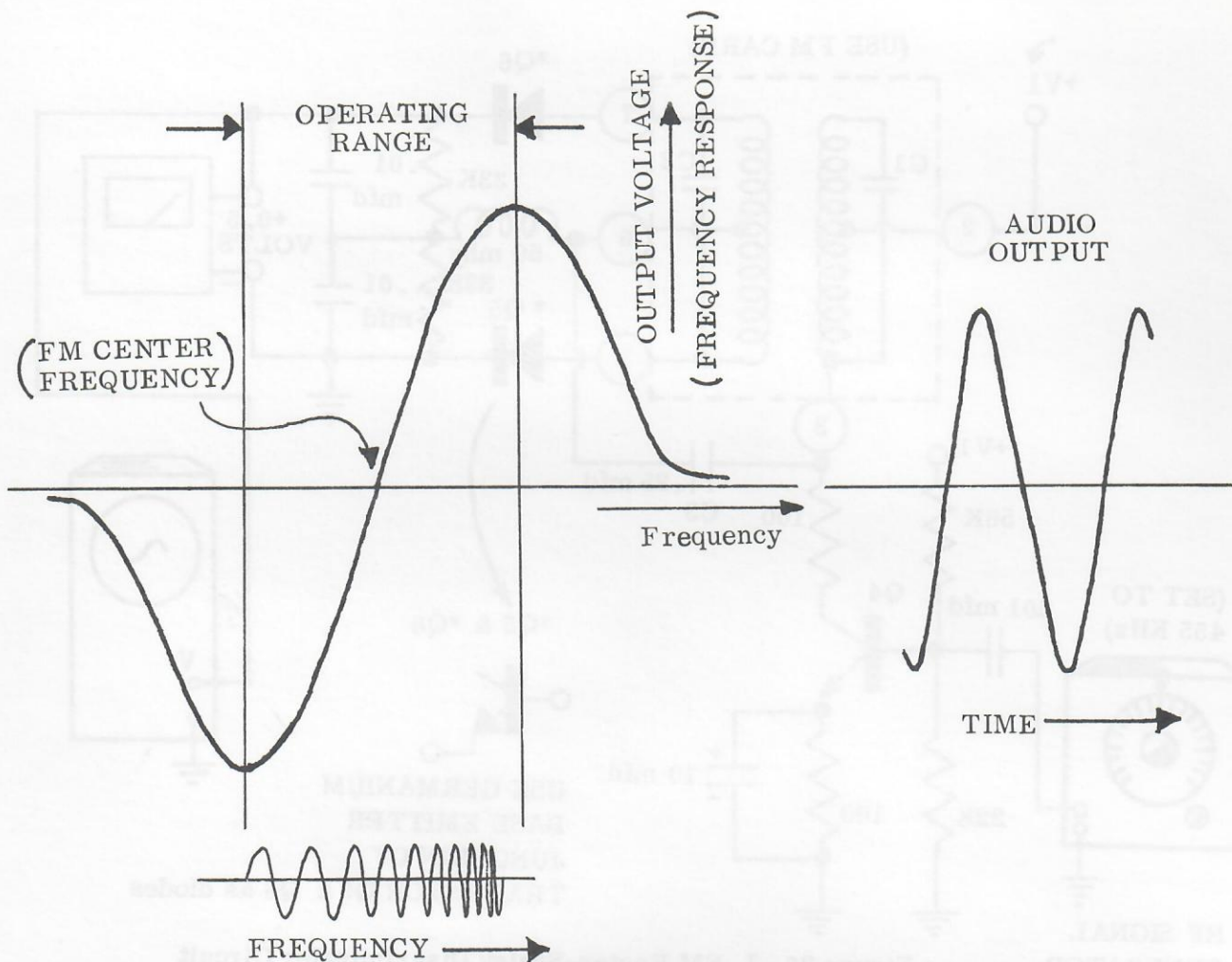


Figure 35 - 2 Discriminator Audio Response

Capacitors C1 and C2 are mounted on the FM CARD and are designed to be tuned at the IF Frequency resonance. Capacitor C3 couples the "phase" of the primary voltage (pin 3) to the secondary (pin 4). As the frequency deviates from resonance, the current phase leads or lags the voltage in the primary. The addition of outputs in the secondary (pins 6 and 7) result in an audio output voltage which is proportional to the frequency (phase) variation. This addition is described in various reference texts using Vector diagrams. Capacitors C4 and C5 are the detector filter capacitors. The detector diodes result in outputs across the 33K resistors, where the polarity of the voltages are in opposite directions and cancel each other at the center frequency to result in a zero voltage output.

Procedure:

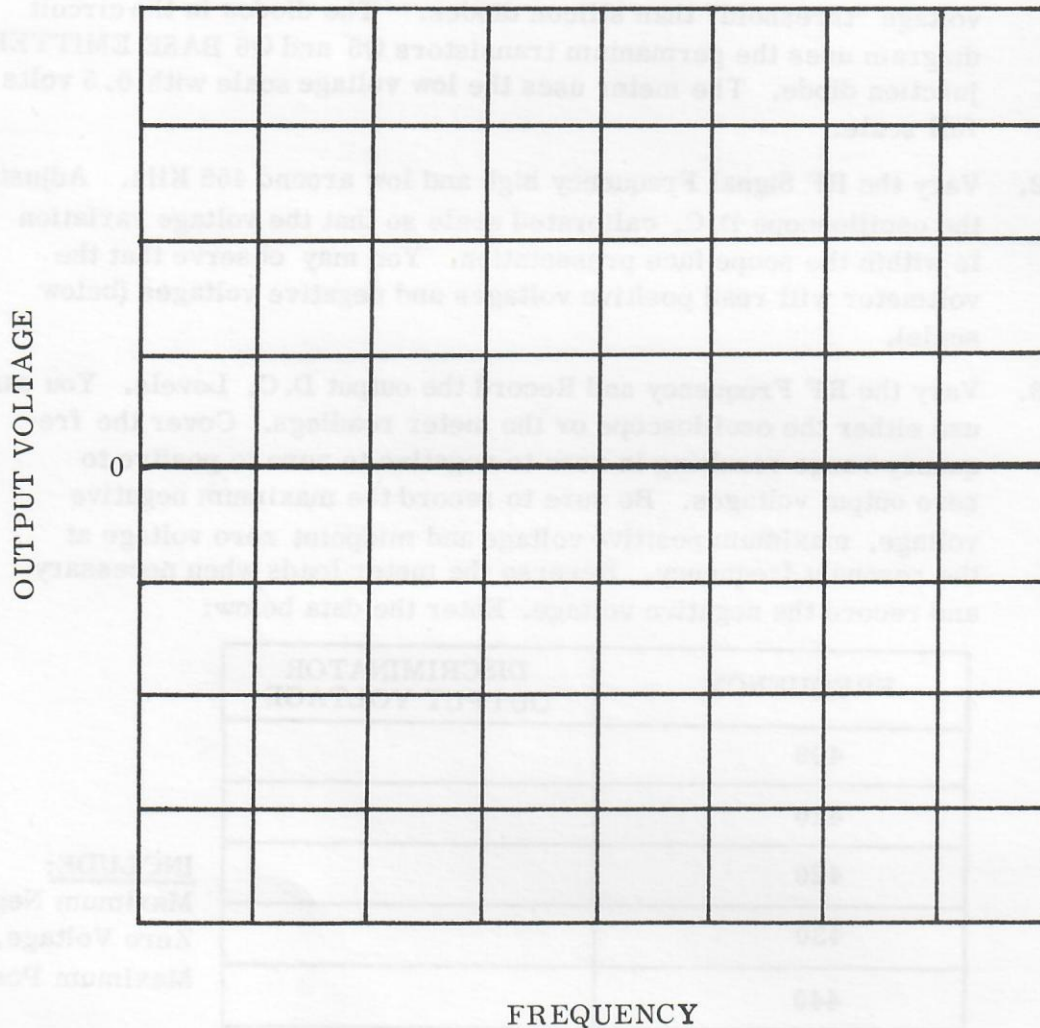
1. Wire the FM Discriminator circuit in Figure 35 - 1. Use a standard RF Signal Generator. The detector diodes are generally Germanium-Diodes which have lower forward resistance and lower forward voltage "threshold" than silicon diodes. The diodes in the circuit diagram uses the germanium transistors Q5 and Q6 BASE EMITTER junction diode. The meter uses the low voltage scale with 0.5 volts full scale.
2. Vary the RF Signal Frequency high and low around 455 KHz. Adjust the oscilloscope D.C. calibrated scale so that the voltage variation is within the scope face presentation. You may observe that the voltmeter will read positive voltages and negative voltages (below scale).
3. Vary the RF Frequency and Record the output D.C. Levels. You can use either the oscilloscope or the meter readings. Cover the frequency range resulting in zero to negative to zero to positive to zero output voltages. Be sure to record the maximum negative voltage, maximum positive voltage and midpoint zero voltage at the resonant frequency. Reverse the meter leads when necessary and record the negative voltage. Enter the data below:

FREQUENCY	DISCRIMINATOR OUTPUT VOLTAGE
400	
410	
420	
430	
440	
445	
450	
455	
460	
465	
470	
480	
500	

INCLUDE:

Maximum Negative,
Zero Voltage, &
Maximum Positive

4. Plot the resultant "S-CURVE" response of the discriminator (output voltage versus frequency) in the graph below:



5. By referring to the above graph, what is the center frequency, and what is useful frequency deviation of the discriminator circuit.

CENTER FREQUENCY = KHz

MAXIMUM FREQUENCY DEVIATION = $\pm$ KHz

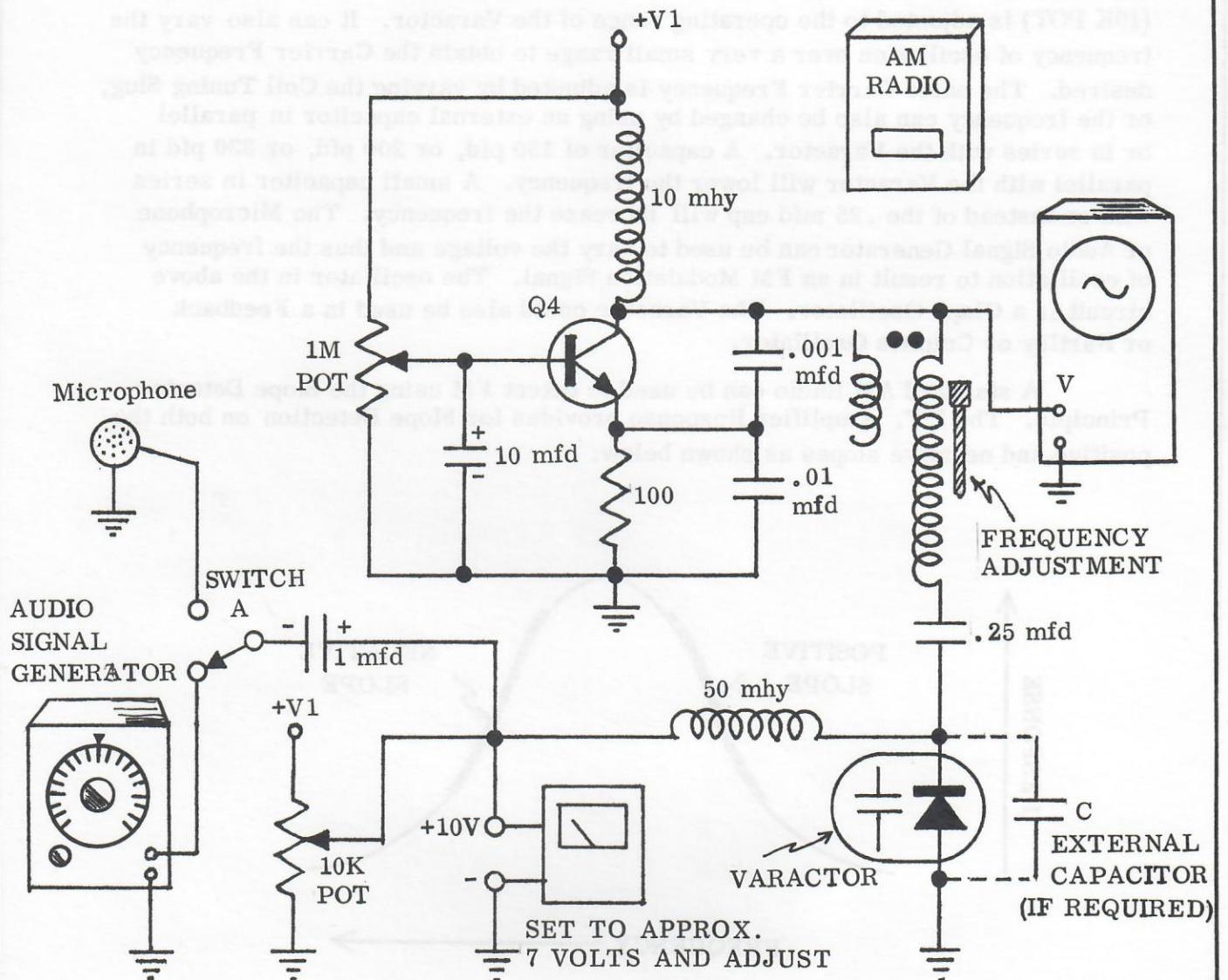


Figure 36 - 1 FM TEST GENERATOR

Objective:

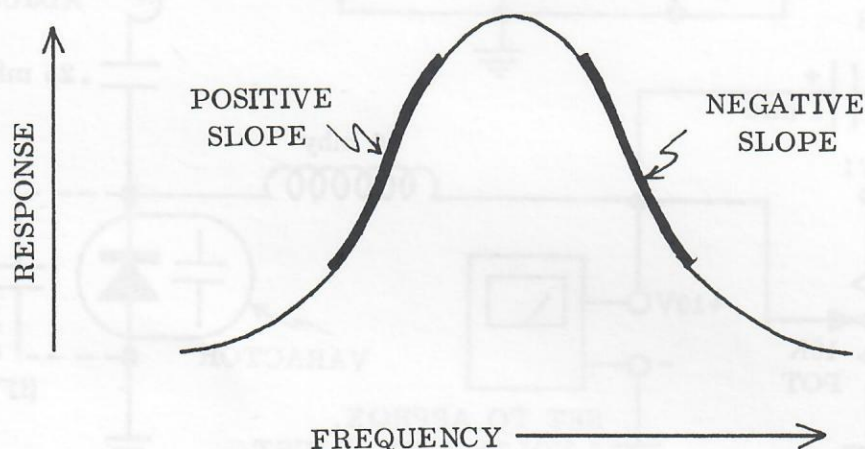
You will build an FM Modulated Oscillator similar to that in an earlier experiment. This oscillator will be used to generate an FM Test Signal which is necessary to test certain types of FM Demodulators and particularly the Ratio Detector.

Description:

The Colpitts, Hartley, Clapp or Feedback Oscillators use an Inductor and Capacitor to determine the oscillation frequency. The capacitance of the Varactor

diode changes as the voltage across the Varactor is varied. The D.C. Voltage (10K POT) is adjusted to the operating range of the Varactor. It can also vary the frequency of oscillation over a very small range to obtain the Carrier Frequency desired. The basic Carrier Frequency is adjusted by varying the Coil Tuning Slug, or the frequency can also be changed by using an external capacitor in parallel or in series with the Varactor. A capacitor of 150 pfd, or 200 pfd, or 330 pfd in parallel with the Varactor will lower the frequency. A small capacitor in series with or instead of the .25 mfd cap will increase the frequency. The Microphone or Audio Signal Generator can be used to vary the voltage and thus the frequency of oscillation to result in an FM Modulation Signal. The oscillator in the above circuit is a Clapp Oscillator. The Varactor could also be used in a Feedback or Hartley or Colpitts Oscillator.

A standard AM Radio can be used to detect FM using the Slope Detector Principle. The I.F. Amplifier Response provides for Slope Detection on both the positive and negative slopes as shown below:



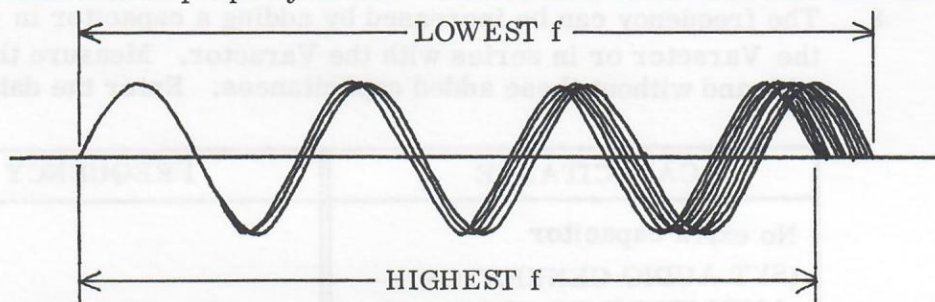
I.F. Pass Band Characteristics

The test generator can be adjusted at an AM Radio Frequency or at the IF Radio Frequency (455 KHz). The Test Generator in this experiment will be adjusted to both an RF Frequency in the AM Band and to the 455 KHz IF Frequency.

Procedure:

1. Wire the circuit in Figure 36 - 1.
2. Adjust the Varactor D.C. Voltage using the 10K Potentiometer to result in a meter reading of approximately 2 volts.

3. Set Switch A DOWN to provide the Audio Signal Generator input. Set the audio voltage amplitude low.
4. Monitor the output signal on the Oscilloscope. Adjust the Oscillator (1M POT) and the Varactor Bias (10K POT) for a steady and stable output waveform. Adjust the Audio Signal Generator frequency at about 1 KHz and at a level to result in a small frequency modulation as shown below: (There may be distortion due to the unidirectional property of the Varactor as it is used in this circuit.)



Sketch the observed waveform below:

5. Use the calibrated horizontal scale on the oscilloscope to determine the oscillation frequency. Enter the data below and then calculate the frequency.

MEASUREMENT	LOWEST f	HIGHEST f
NUMBER OF CYCLES:		
TIME:		

CALCULATION	LOWEST f	HIGHEST f
FREQUENCY:		

6. This frequency can be varied by rotating the Tuning Slug on the RF Coil. Rotate the knob by a small amount.

Does the frequency change? _____

7. The frequency can also be varied by slightly adjusting the D.C. Bias on the Varactor. Adjust the Bias 10K POT by a small amount.

Does the frequency change? _____

8. The frequency can be increased by adding a capacitor in parallel with the Varactor or in series with the Varactor. Measure the frequency with and without these added capacitances. Enter the data below:

CAPACITANCE	FREQUENCY
No extra capacitor (SET AUDIO GENERATOR AMPLITUDE TO ZERO) i. e. No F. M.	
150 pfd Capacitor in parallel with Varactor	
220 pfd Capacitor in parallel with Varactor	
Series 150 pfd Cap. (Substitute 150 pfd for 0.25 mfd Cap.)	
Series 220 pfd Cap. (Substitute 220 pfd for 0.25 mfd Cap.)	

9. Replace the 220 pfd Cap with the 0.25 mfd Cap from the original circuit. The AM Radio can also be used to demodulate FM Signals using the AM Detector as an FM Slope Detector.

Adjust the Oscillator Frequency to some frequency within the Radio Band of 550 KHz to 1600 KHz by adjusting the Tuning Slug. It may be necessary to increase the frequency by a series capacitor, that is, a 150 or 220 pfd cap is used to replace the 0.25 mfd Cap. The oscilloscope can be used to indicate the frequency; recalling that 1 MHz is equal to 1 Microseconds.

10. Adjust the Audio Signal Generator for some small FM Modulation. Tune the radio to detect the modulated tone. Observe that there is FM Slope Detection at two adjacent frequencies (lower and upper slopes) with a null in-between.

Are you able to receive a Tone? _____ Do you observe the null? _____

What is the transmitted and detected frequency? (Use scope and radio dial.)

TRANSMISSION FREQUENCY =

11. Set Switch A UP with the Microphone as an input. Speak into the Microphone and listen to the reception on the AM/FM Radio.

Are you able to receive your voice transmission? _____

12. Remove any series capacitor if one was necessary and replace it with the series 0.25 mfd capacitor.

Was a series capacitor necessary? _____

What size was used? _____

13. The AM Radio can be used to CALIBRATE the FM Test Oscillator at the IF Frequency.

Adjust the oscillator frequency for the IF Frequency of 455 KHz. Be sure to use a small amount of FM Modulation. The IF Amplifier will receive the signal directly if the AM Radio is placed near to the oscillator output. Once the Oscillator is adjusted to the IF frequency, it will be detected at any setting of the Radio tuning dial because it is received through the IF Amplifiers, not through the RF Converter or Mixer circuits. It may be necessary to use a capacitor, 150 pfd or 200 pfd in parallel with the Varactor to lower the oscillation frequency.

Adjust the Tuning Slug and then use the 10K POT to vary the Varactor Voltage to obtain a 455 IF Frequency. This is determined when the Tone is heard over the radio. The tuned radio is used as a Reference in order to Tune or Calibrate the FM test Oscillator.

Observe that there are two close tuning points with a null in-between as the tuning scans the bandpass curve, passing between the positive and negative slopes with its in-between peak. Tuning is actually proper at the in-between null. If an AM Radio is not available, set 455 KHz using the oscilloscope time base calibration.

Are you able to tune the oscillator to 455 KHz (at the null)? _____

TRANSMISSION FREQUENCY

11. Set Switch A UP with the Microphone as an input. Speak into the Microphone and listen to the reception on the AM/FM Radio.

Are you able to receive your voice transmission? _____

12. Remove any series capacitor if one was necessary and replace it with the series 0.25 μ F capacitor.

Was a series capacitor necessary? _____

What else was done? _____

13. The AM Radio can be used to CALIBRATE the FM Test Oscillator at the IF frequency.

Adjust the oscillator frequency for the IF frequency of 455 KHz. Be

care to use a small amount of FM Modulation. The IF Amplifier will

receive the signal directly if the AM Radio is placed near to the

oscillator output. Once the Oscillator is adjusted to the IF frequency,

it will be detected at any setting of the Radio tuning dial because it is

received through the IF Amplifier, not through the RF Converter or

Mixer circuit. It may be necessary to use a capacitor, 150 pF or

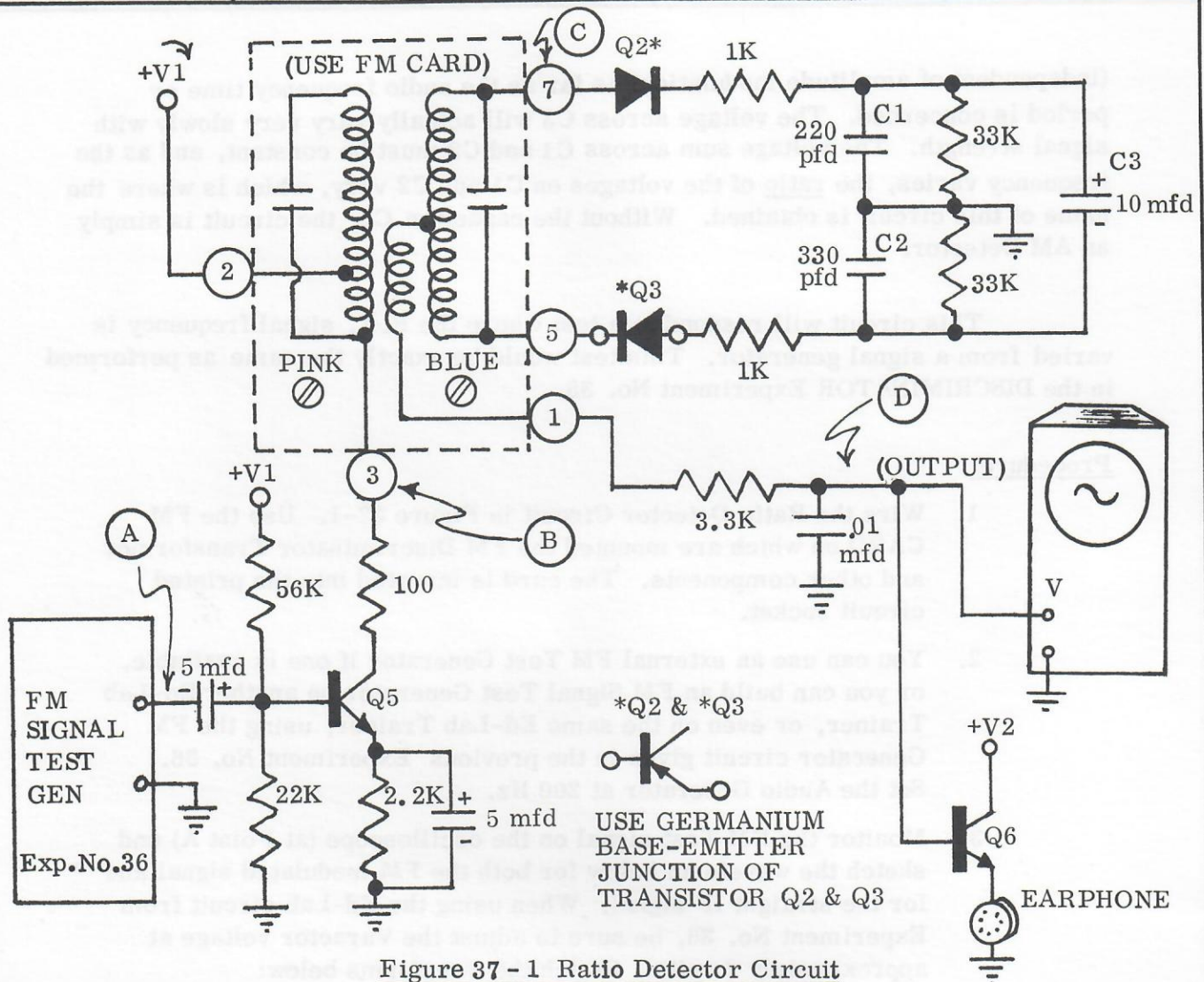
200 pF in parallel with the Variable to lower the oscillation frequency.

Adjust the Tuning Knob and then use the 100 PPT to vary the Variable Voltage to

obtain a 455 IF frequency. This is determined when the Tone is heard over the

radio. The fixed radio is used as a reference in order to tune or Calibrate

the FM Test Oscillator.

Objective:

You will build and test the Ratio Detector circuit and measure the audio signal output.

Description:

The Ratio Detector circuit is shown above in Figure 37 - 1. Transistor Q4 drives the IF Discriminator Transformer as in previous experiments for the Slope Detector and Foster-Seeley Discriminator. The Ratio Detector circuit suppresses amplitude noise signals without using limiter stages. Notice that the bottom diode is reversed from the Discriminator Circuit. This results in what appears as two detector circuits with the voltage across the Detector Capacitors C1 and C2 in the direction where they add. The Capacitor, C3, is a high value (+10 mfd) so that the voltage sum across C3 (which is the sum across C1 and C2) is constant

(independent of amplitude modulation) as far as the audio frequency time or period is concerned. The voltage across C3 will actually vary very slowly with signal strength. The voltage sum across C1 and C2 must be constant, and as the frequency varies, the ratio of the voltages on C1 and C2 vary, which is where the name of this circuit is obtained. Without the capacitor C3, the circuit is simply an AM Detector.

This circuit will respond to a test where the R.F. signal frequency is varied from a signal generator. This test would be exactly the same as performed in the DISCRIMINATOR Experiment No. 35.

Procedure:

1. Wire the Ratio Detector Circuit in Figure 37-1. Use the FM CARD on which are mounted the FM Discriminator Transformer and other components. The card is inserted into the printed circuit socket.
2. You can use an external FM Test Generator if one is available, or you can build an FM Signal Test Generator on another Ed-Lab Trainer, or even on the same Ed-Lab Trainer, using the FM Generator circuit given in the previous Experiment No. 36. Set the Audio Generator at 200 Hz.
3. Monitor the FM Test signal on the oscilloscope (at Point A) and sketch the waveform below for both the FM modulated signal and for the straight IF signal. When using the Ed-Lab circuit from Experiment No. 36, be sure to adjust the Varactor voltage at approximately 2 volts. Sketch the waveforms below:

WAVEFORM A

(FM MODULATED SIGNAL)

WAVEFORM B

(AMPLIFIER OUTPUT)

4. Monitor the discriminator transformer output at point C (Pin 7) and adjust the RF Test Oscillator Center Frequency to correspond to the Resonant Frequency of the Transformer for maximum output. You can adjust the RF Frequency on the FM Test Generator with the tuning slug on the Ed-Lab Test Generator or you can tune the Discriminator Coil (BLUE Tuning Slug).

CAUTION: EXTREME CARE MUST BE TAKEN WHENEVER ATTEMPTING TO TUNE THE COIL. THE SLUGS ARE SOFT AND MAY BE RUINED BY USING SHARP TOOLS OR BY ATTEMPTING TO TURN THE SLUG PAST ITS NORMAL RANGE WHERE IT IS HARD TO TURN.

5. Monitor the audio output using the oscilloscope and with the earphone. Vary the audio frequency tone and amplitude and monitor the audio output at point D . Sketch the Ratio Detector output below:

WAVEFORM C

RATIO DETECTOR AUDIO OUTPUT

A schematic diagram of an AM-FM Radio is shown below in Figure 37 - 2. There is a separate converter for the AM (using Transistor Q3) and a separate converter for the FM (using Transistor Q2). The IF Amplifiers (Transistors Q4 and Q5) have both the AM IF Transformer (455 KHz) and the FM IF Transformer (10.7 MHz) as collector loads. Observe the FM Ratio Detector (Diodes D3 and D4) and the AM Detector (Diode D5).

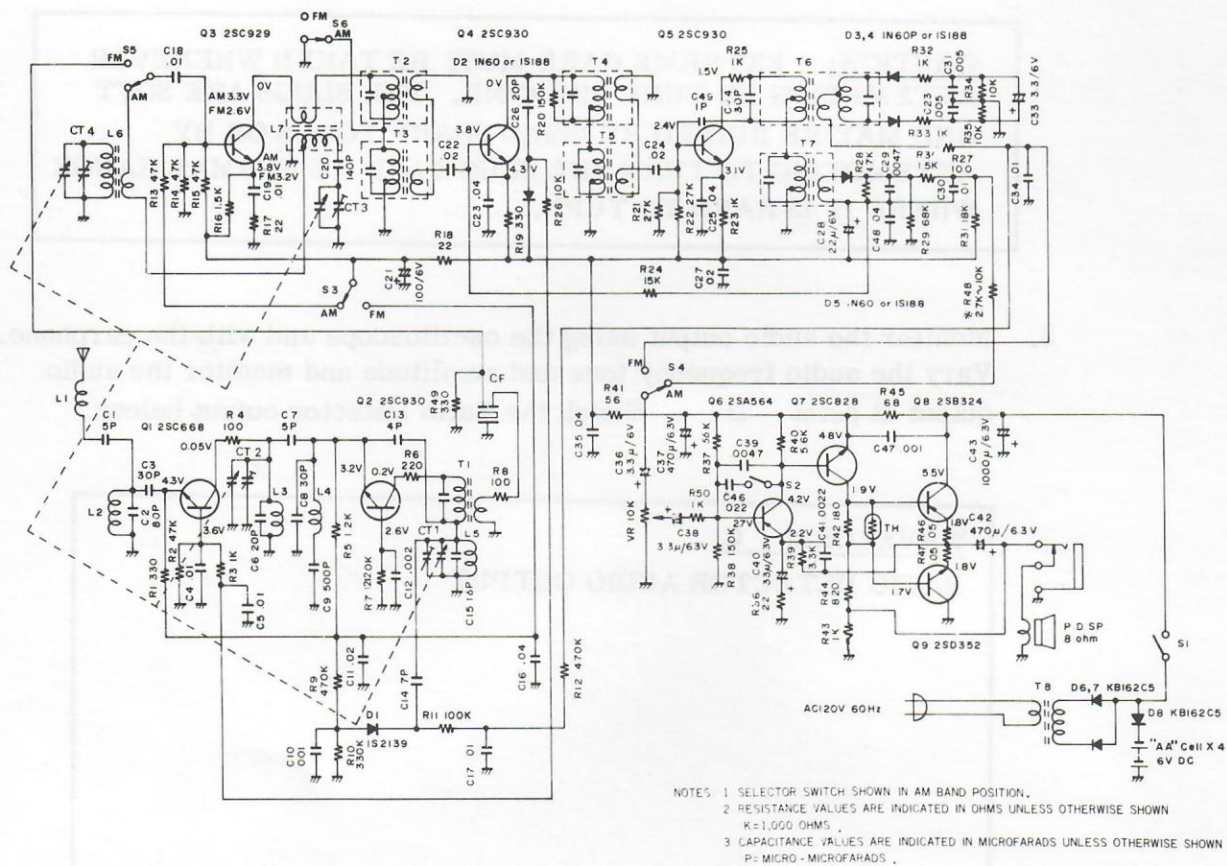
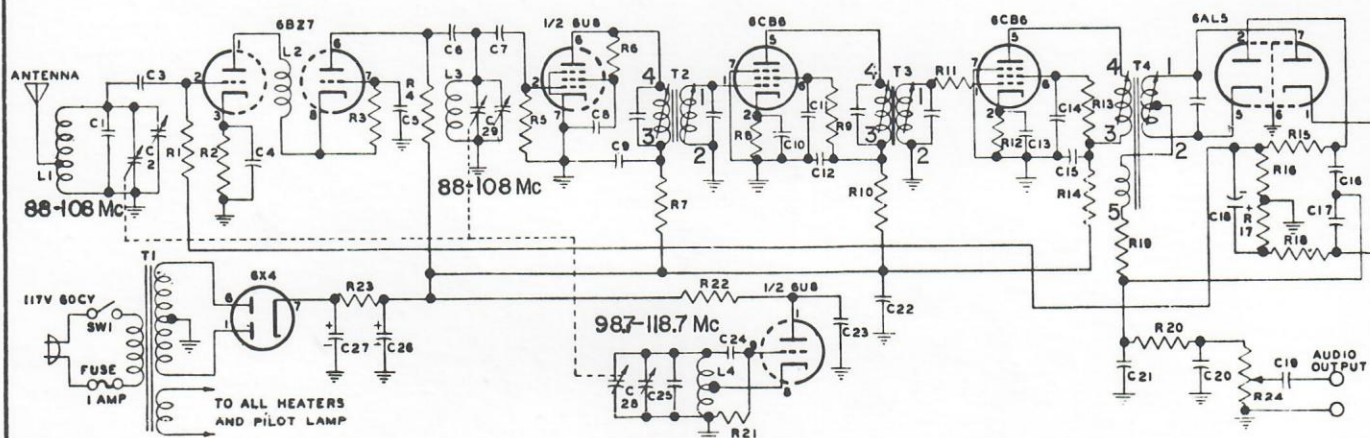


Figure 37 - 2 AM-FM Radio Schematic

A schematic Diagram of an FM Tuner (not including the Audio Amplifier) is shown below in Figure 37 - 3. Observe three Tube IF Amplifiers (1/2 6U8, and 2 of 6CB6), a Local Oscillator (1/2 6U8), an input RF Amplifier (6BZ7), Ratio Detector Vacuum tube diodes (6AL5), and a Full Wave Power Supply (6X4). The Mixing or Conversion is actually not shown on the diagram but occurs as an interaction between the two sections of Tube 6U6 which have the Local Oscillator and the first IF Amplifier.

FM TUNER



C1—12 μ f
C2 C28 C29—Tuning Capacitors
and Associated Trimmers
C3 C7 C24—47 μ f
C4 C5 C8 C20 C23—0.001 μ f
C6—3.3 μ f
C9 C10 C11 C12 C13 C14 C15 C22—
0.005 μ f
C16 C17 C21—270 μ f
C18—10 μ f 50V
C19—0.05 μ f
C25—10 μ f
C26 C27—20 μ f 350V

L1—Antenna Coil
L2 L3—RF Coils
L4—Oscillator Coil
R1 R3—470 K
R2 R12 R19—68 Ω
R4 R7—10 K
R5—1 Meg
R6—100 K
R8—150 Ω
R9 R13 R20—68 K
R10 R14—2.2 K
R11—47 Ω
R15—1.5 K

R16 R17 R22—6.8 K
R18—1 K
R21—22 K
R23—1.5 K 5Watt
R24—1 Meg Pot.
SW1—On-Off Switch
T1—Power Transformer:
Pri—117V, 60CY
Sec—480V CT, 50Ma; 6.3V,
2.5A
T2 T3—10.7 Mc IF Transformers
T4—10.7 Mc Ratio Detector
Transformer

All resistors $\frac{1}{2}$ watt unless otherwise specified

Figure 37 - 3 FM Tuner Schematic Diagram

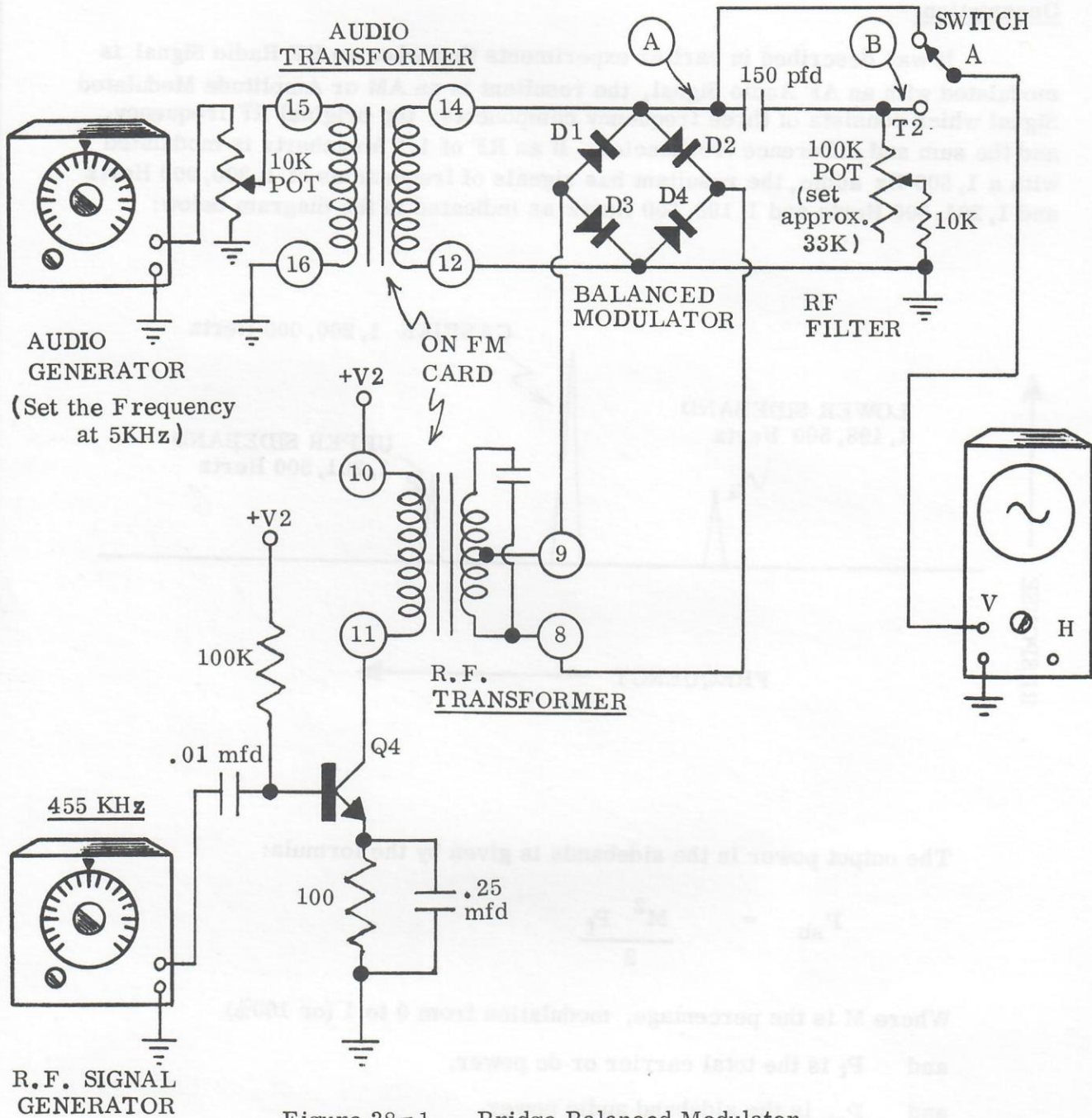


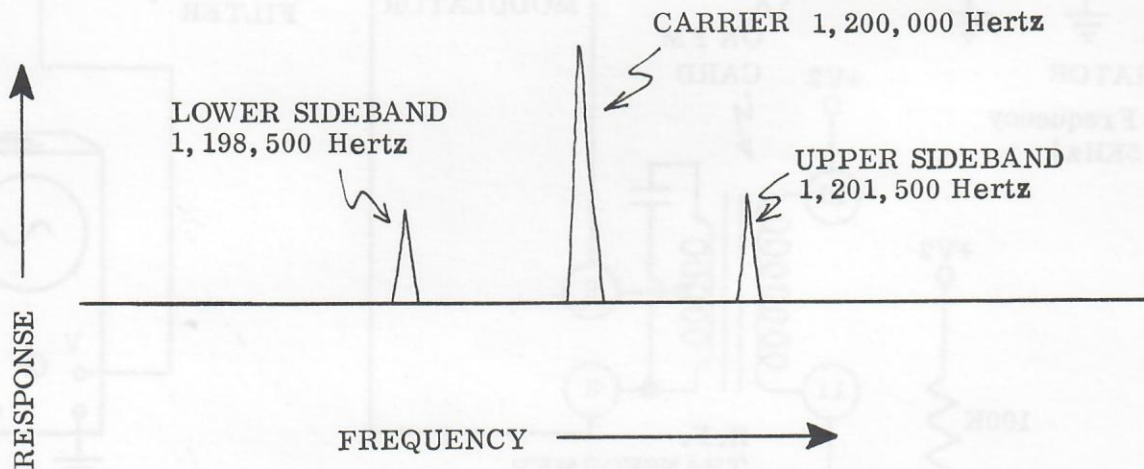
Figure 38-1 Bridge Balanced Modulator

Objective:

You will review the concepts of Suppressed Carrier and Single Sideband Modulation and you will test a Shunt Balanced - Modulator.

Description:

It was described in earlier experiments that when an RF Radio Signal is modulated with an AF Audio Signal, the resultant is an AM or Amplitude Modulated Signal which consists of three frequency components; the original RF frequency, and the sum and difference frequencies. If an RF of 1.2 Megahertz is modulated with a 1,500 Hz audio, the resultant has signals of frequencies of 1,200,000 Hertz and 1,201,500 Hertz and 1,198,500 Hertz as indicated in the diagram below:



The output power in the sidebands is given by the formula:

$$P_{sb} = \frac{M^2 P_t}{2}$$

Where M is the percentage, modulation from 0 to 1 (or 100%)

and P_t is the total carrier or dc power,

and P_{sb} is the sideband audio power.

Thus if the carrier transmitter power is 500 watts, and the percentage modulation is 80% or 0.8, the power in the sidebands is:

$$P_{sb} = \frac{(.8)^2 500}{2} = 160 \text{ watts}$$

The total transmitted power is 660 watts. But only one sideband is necessary to contain all of the information. If we cut-out the carrier and the lower sideband, and received only a single frequency of 1,203,429 Hertz, we would know that the transmitted audio signal is 3,429 Hz. Thus, only one sideband or 80 watts is required instead of the total of 660 watts. In addition, we could transmit another signal in the lower sideband. The disadvantage of the sideband system is that more complicated transmitter and receiver equipment is required.

A system with both sidebands and no carrier is called: **DOUBLE SIDEBAND SUPPRESSED CARRIER** (used in FM Stereo).

A system with the carrier and only one sideband has a **SINGLE SIDEBAND WITH CARRIER** (used in Video or TV Picture Transmission).

The single sideband only systems (SSB) use either **UPPER SINGLE SIDEBAND (USB)** or **LOWER SIDEBAND (LSB)** and thus two radio stations or channels can be transmitted over the same bandwidth used in normal AM Transmission. It is noted that the sideband systems apply only to the Amplitude Modulated Systems.

A **BALANCED SHUNT MODULATOR** is shown in Figure 38 - 1. The RF or IF Frequency (455 KHz) is applied via the IF Transformer to alternately short and open the output of the audio transformer. The diode bridge circuit shorts the output for both positive and negative audio voltages. Unlike a "Switched-Modulator" circuit, the "two-directional" or balanced diode bridge results in a zero output signal corresponding to zero audio resulting in a **SUPPRESSED CARRIER DOUBLE SIDEBAND OUTPUT**. The Balanced Modulator or Chopped-Shunt Modulator output (at point A) appears as shown below in Figure 38 - 2. The RF R-C Filter removes the low frequency components and the output resembles the familiar AM Modulated Waveform as shown in Figure 38 - 3.

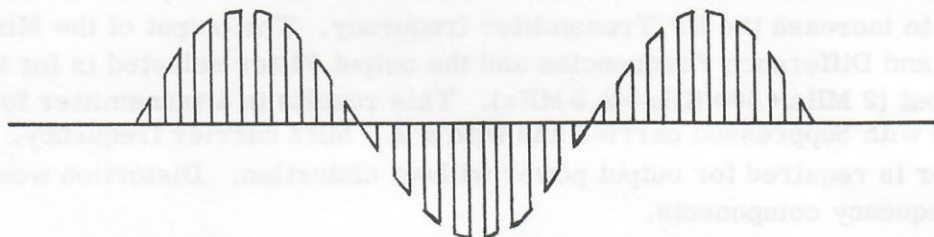


Figure 38 - 2 Balanced Modulator Output

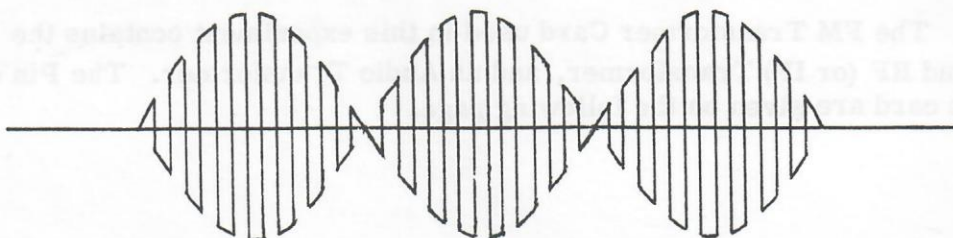


Figure 38 - 3 Filter Output

A Single Sideband Transmitting System is shown in the Block Diagram in Figure 38-4.

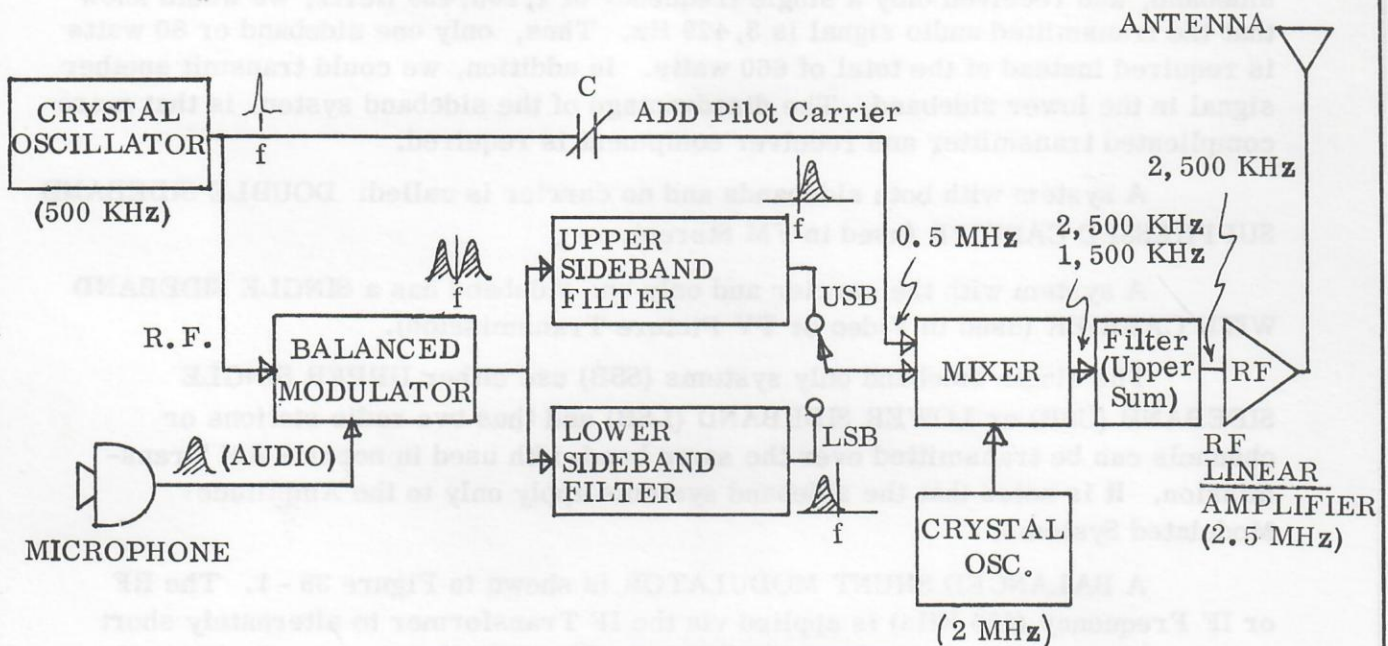


Figure 38-4 SSB TRANSMITTER

The Carrier Frequency is set by the Crystal Oscillator (at 500 KHz). The Balanced Modulator output contains the Upper and Lower Sidebands which are separated by sharp filters. A switch is used to select either the Upper or Lower Sidebands. A small amount of Carrier frequency is added as a "Pilot" signal so that the receiver can add a full carrier later to obtain a signal that can be easily detected. Another standard "mixer" is used with another Crystal Oscillator (2 MHz) to increase the RF Transmitter frequency. The output of the Mixer contains the Sum and Difference Frequencies and the output Filter selected is for the Mixer Sum output ($2 \text{ MHz} + 500 \text{ KHz} = 2.5 \text{ MHz}$). This results in a transmitter for an Upper Sideband with Suppressed carrier and with a 2.5 MHz carrier frequency. A Linear Amplifier is required for output power without distortion. Distortion would add other frequency components.

The FM Transformer Card used in this experiment contains the Discriminator Coil, and RF (or IF) Transformer, and an Audio Transformer. The Pin connections for this card are given on the following page.

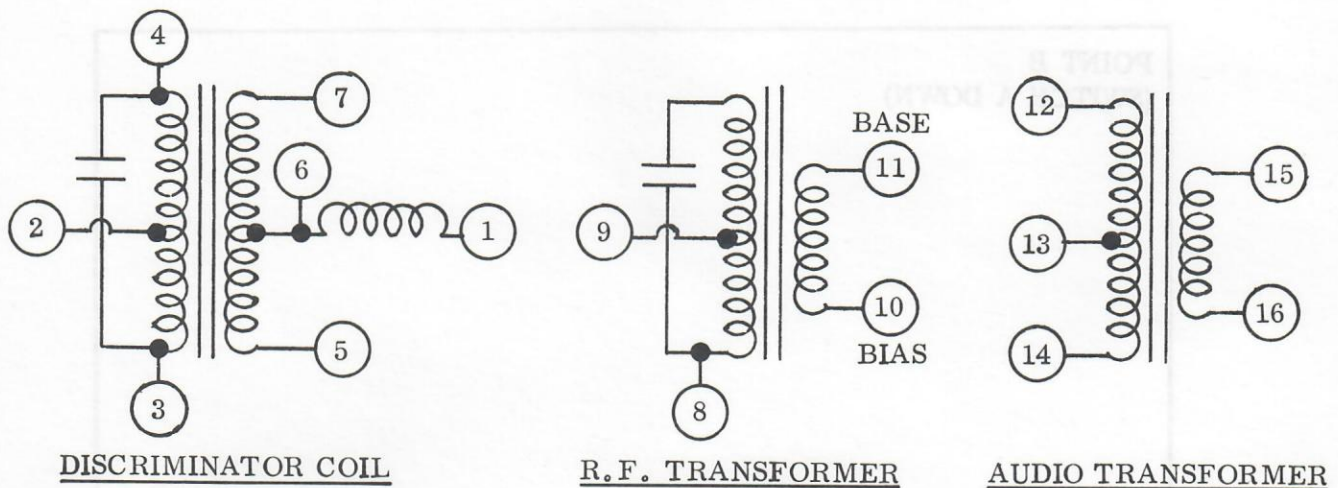


Figure 38 - 5 FM Transformer Card

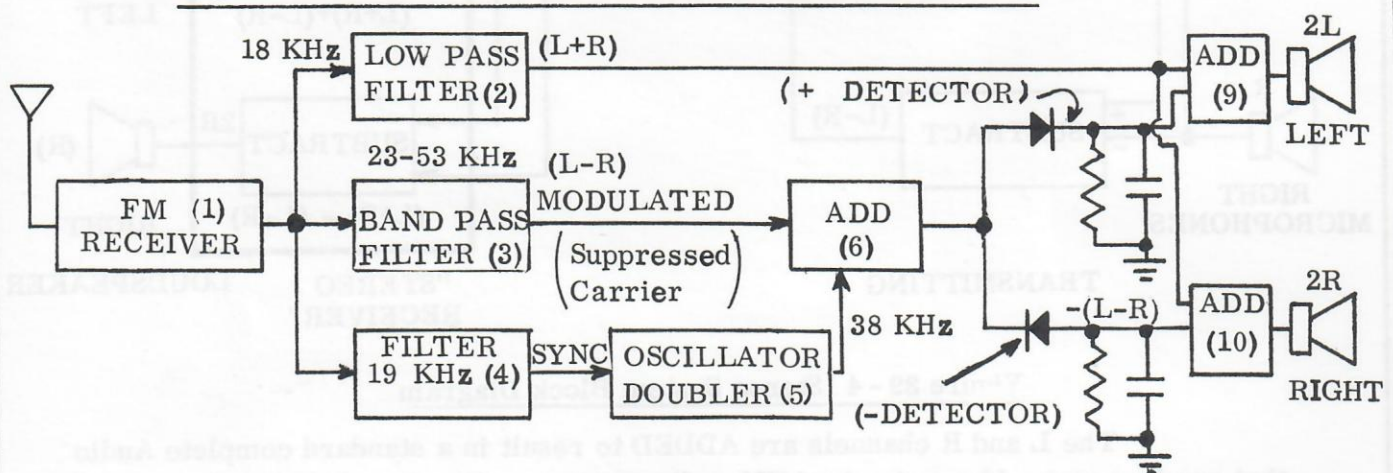
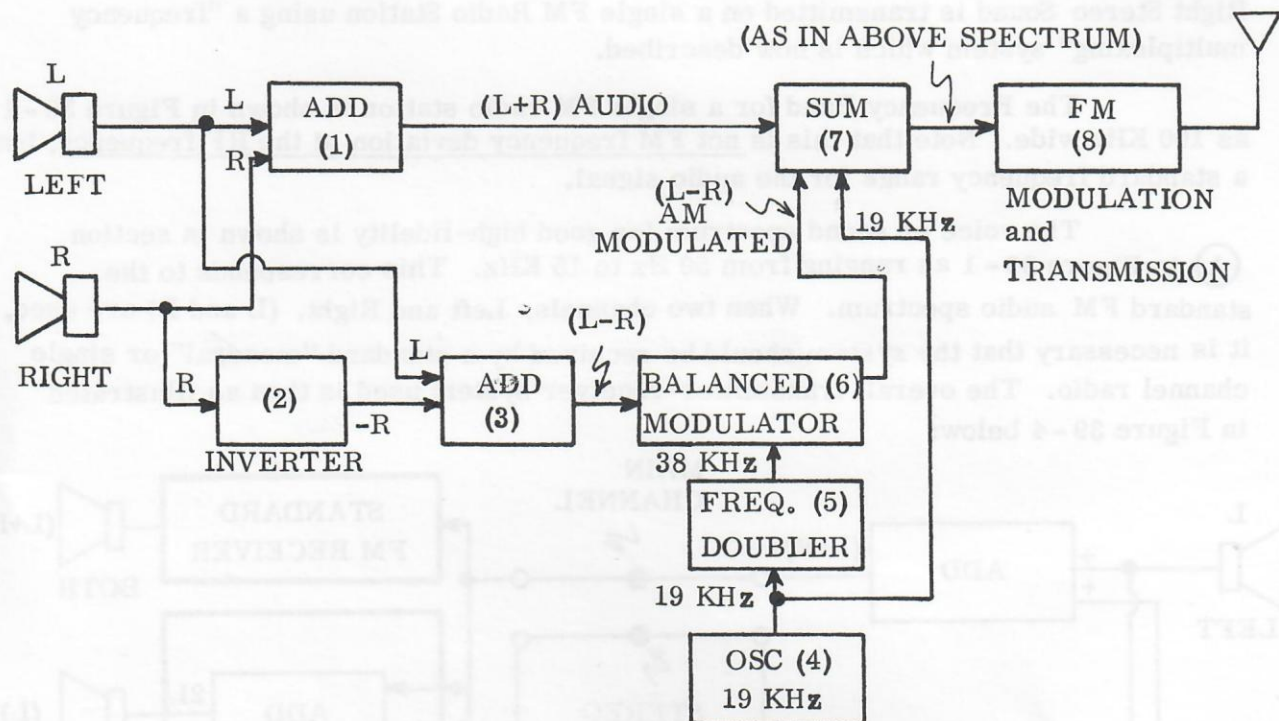
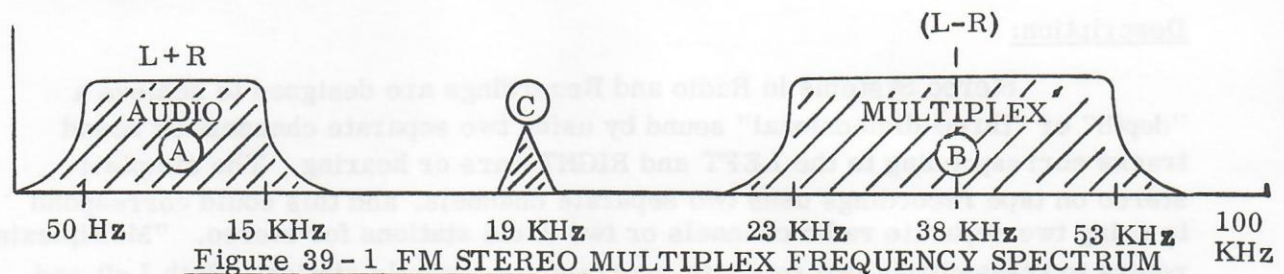
Procedure:

1. Wire the Balanced Modulator Circuit in Figure 38 - 1. Set the Audio Signal to a high level.
2. Monitor the output at Point A (Switch A UP) and adjust the RF Generator Frequency at approximately 455 KHz to the frequency resulting in a maximum output. This corresponds to the resonant frequency of the R.F. Transformer.
3. Observe the waveforms at the Modulator output (POINT A) with Switch A UP, and at the Filter Output (POINT B) with Switch A DOWN. Adjust the 100K POT about 33K to result in a symmetrical output waveform. Sketch the waveforms below and on the following page.

POINT A
(SWITCH A UP)

POINT B
(SWITCH A DOWN)

4. Do these outputs correspond to the expected outputs shown in the description?
5. Set the Audio Signal down to zero (set the 10K POT to zero). Observe the output signals at Point A and Point B. Is the carrier present with no audio signal? The balanced modulator eliminates or suppresses the carrier. If some small carrier signal voltage is present, you may want to measure this carrier signal voltage level, and then measure the voltage level with an audio signal, and then calculate the ratio audio output to carrier output as a measure of carrier suppression.
6. The above output is a Double Sideband Suppressed Carrier Signal. If only a Single Sideband is desired, an output filter is used to eliminate one of the sidebands as shown in the Block Diagram in Figure 38-4.

Objective:

You will review the concept of Stereo Multiplexing in an FM Radio. You build and test an FM Encoder and FM Decoder.

Description:

Stereo Systems in Radio and Recordings are designed to achieve a "depth" or "three-dimensional" sound by using two separate channels or sound tracks corresponding to the LEFT and RIGHT ears or hearing. The simplest stereo on tape recordings uses two separate channels, and this could correspond to using two separate radio channels or two radio stations for stereo. "Multiplexing" refers to transmitting two separate programs on a single station. Both Left and Right Stereo Sound is transmitted on a single FM Radio Station using a "frequency multiplexing" system which is now described.

The Frequency Band for a single FM radio station is shown in Figure 39-1 as 100 KHz wide. Note that this is not FM frequency deviation at the RF frequency, but a standard frequency range for the audio signal.

The voice or sound spectrum for good high-fidelity is shown in section (A) in Figure 39-1 as ranging from 50 Hz to 15 KHz. This corresponds to the standard FM audio spectrum. When two channels, Left and Right, (L and R) are used, it is necessary that the system should be received by a standard "monoral" or single channel radio. The overall transmitter-receiver system used is then as illustrated in Figure 39-4 below:

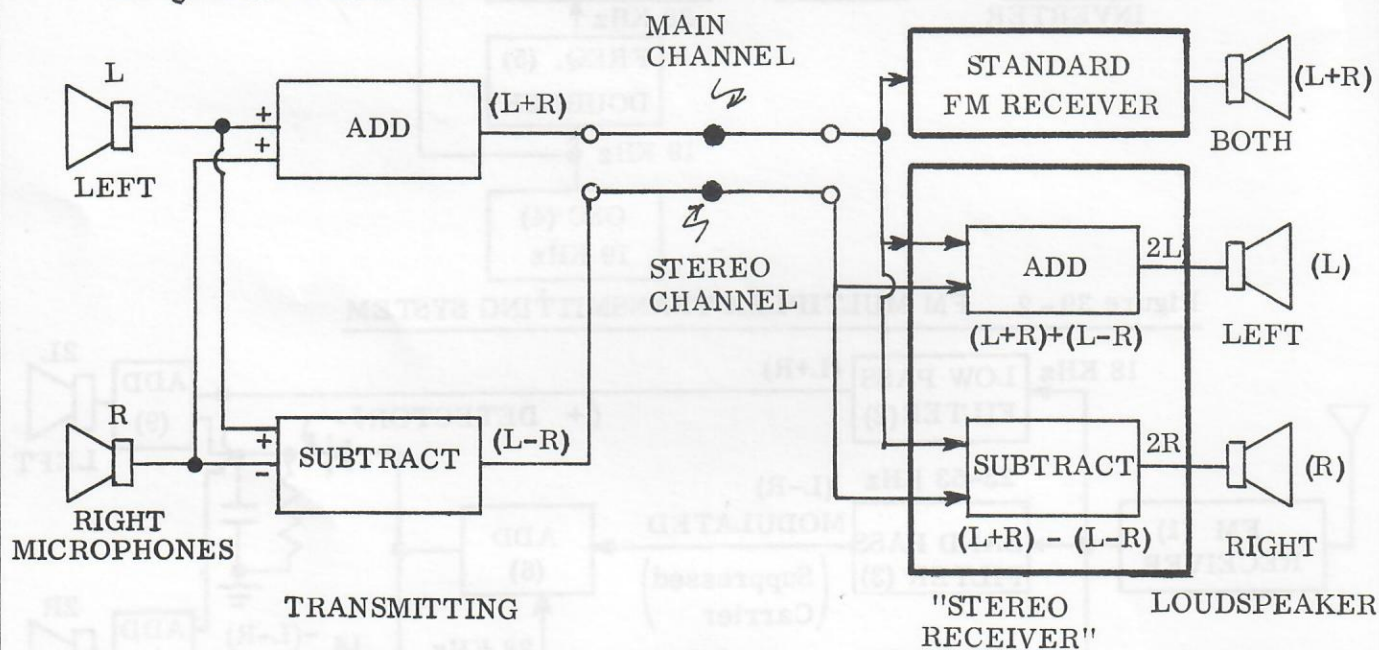


Figure 39-4 Stereo System Block Diagram

The L and R channels are ADDED to result in a standard complete Audio that can be received by a standard FM radio receiver. The L and R channels are also SUBTRACTED resulting in another channel. The Stereo Receiver adds the two channels to obtain the LEFT sound, and subtracts the two channels to obtain the RIGHT sound as indicated in Figure 39-4.

The two channels (L+R) and (L-R) are both transmitted over one single radio station by "frequency multiplexing". The (L-R) channel is used to modulate a 38 KHz carrier frequency resulting in sidebands extending down to 23KHZ (38 KHz-15 KHz) and up to 53 KHz (38 KHz + 15 KHz). This is illustrated in Figure 39 - 1 in the frequency band labeled (B). The two channels are now in different frequency bands; they can be added together, transmitted over a single station, and then separated by filters.

The system for Transmitting is shown in Figure 39 - 2 and each block is now described: (1) The Left and Right Channels are Added (L+R), (2) The Right Channel is "Inverted" (-R) and (3) Added to (L) to obtain the difference (L-R), (4) a 19 KHz Oscillator, is (5) Doubled in frequency to obtain 38 KHz; to (6) Modulate the (L-R) channel thus raising the frequency band for this difference channel. A "Balanced Modulator" (6) is used resulting in the elimination of the carrier of 38 KHz resulting in a "Double Sideband-Suppressed Carrier" output. It is necessary then to insert the carrier information later at the receiver and so the 19 KHz signal is added to the transmitted information as indicated in Figure 39 - 1 with the letter (C). The (L+R) and (L-R) and 19 KHz are summed (7) and then FM Modulated and transmitted (8).

The Receiving System must separate the two channels, add the 38 KHz carrier back to the systems, AM Detect the (L-R) channel and add and subtract the (L+R) and (L-R) channels to obtain the separate Left and Right audio channels. This is illustrated in Figure 39 - 3 which is described below referring to the numbered blocks. The FM Receiver (1), FM Demodulates the signal (using a Discriminator or Ratio Detector) to result in an audio signal with the total frequency spectrum (100 KHz) as given by Figure 39 - 1 with both channels. An 18 KHz LOW PASS FILTER (2) results in the (L+R) channel output. A 23 KHz to 53 KHz BAND PASS FILTER (3) separates the (L-R) "modulated" signal. A tuned 19 KHz FILTER AMPLIFIER (4) selects the 19 KHz signal (called the "pilot sub-carrier") which synchronizes a tuned oscillator (5) to result in the 38 KHz original carrier signal. This 38 KHz signal is ADDED (6) to the Sidebands to result in the complete AM signal with carrier. This signal is AM (+) DETECTED (7) to result in the Audio (L-R) and is (-) DETECTED (8), with an AM detector with a reversed diode, to result in the audio signal for (-) (L-R). The (L+R) and (L-R) are ADDED (9) to obtain the LEFT Stereo Channel, and the (L+R) and (-) (L-R) are ADDED (10) to obtain the RIGHT Stereo channel.

The (+) and (-) Detectors and the Adders, which are implemented using two resistors, are Circuits which can be drawn in a square arrangement called a MATRIX illustrated in Figure 39 - 5 on the following page.

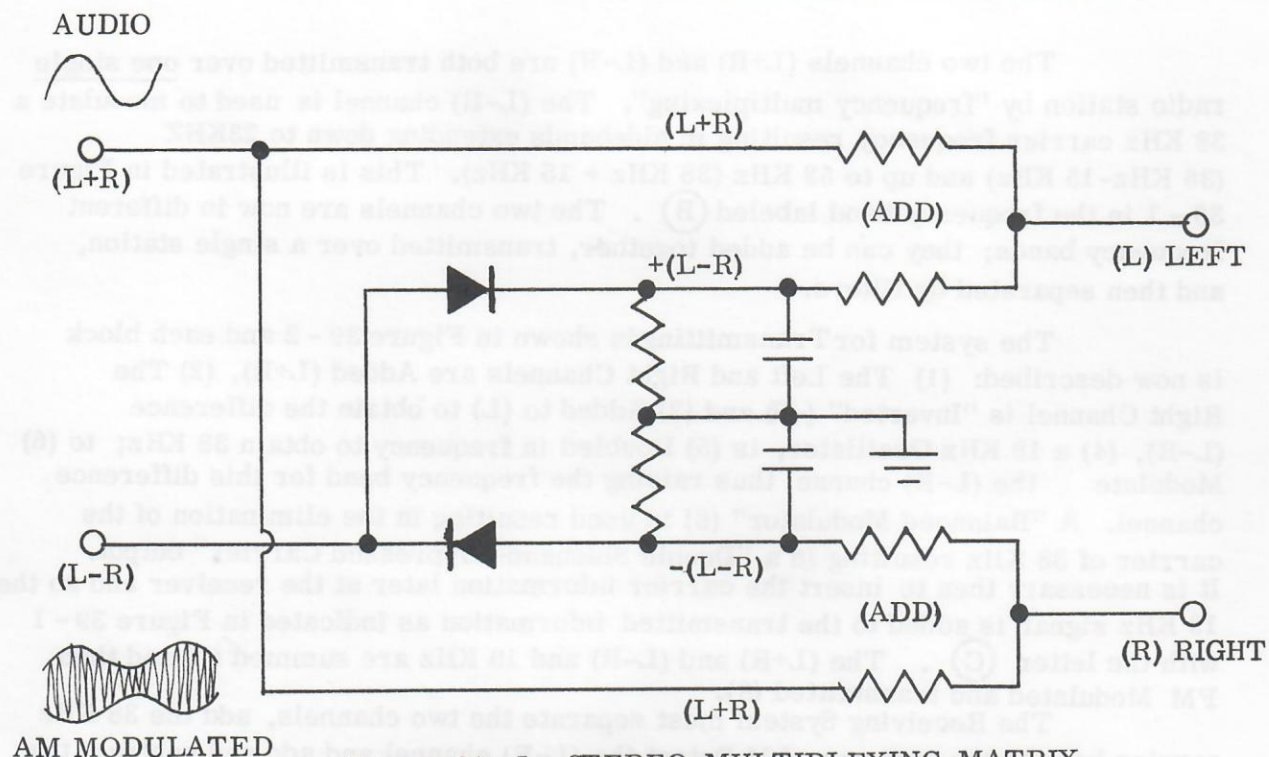


Figure 39-5 STEREO MULTIPLEXING MATRIX

This experiment demonstrates the process of Encoding the two stereo channels: $(L+R)$ and $(L-R)$, and the process of Decoding the original independent L and R channels. The reason that the two channels must be encoded as the sum and difference, and not as separate L and R channels, is that the standard FM Stereo System must be COMPATIBLE with standard monoral FM Receivers. The experiment circuit is shown in Figure 39-6. The Right Signal Generator is connected to a "Phase Splitter Circuit" which is an amplifier with outputs taken from both the Emitter and Collector. The Emitter Output is equal to the Base Input (R). The Collector output is negative $(-R)$ or reverse-phased with the input. The Left and Right signals are added by the two 33K Resistors. The $(L-R)$ Stereo Channel is normally used to AM Modulate a 38 KHz carrier frequency.

In this experiment, the $(L-R)$ stereo channel is connected to another Phase Splitter (Q5) and to generate $-(L-R)$ at the Collector and $(L-R)$ at the Emitter. Switch A is used to select either one of these signals. When Switch A is UP, the $-(L-R)$ signal is connected to one terminal of the 1M Balance POT and $(L+R)$ is connected to the other terminal of the 1M POT. When the 1M POT is properly adjusted or balanced, the output will be $(L+R)-(L-R) = 2R$ so the RIGHT Channel is available on the output line and the LEFT Channel is cancelled or removed. When Switch A is DOWN, the $(L-R)$ Signal is connected to the 1 Meg Balance Pot. When the 1 MEG POT is properly adjusted, the output is $(L+R)+(L-R) = 2L$ and the LEFT Channel is the output and the RIGHT Channel is cancelled.

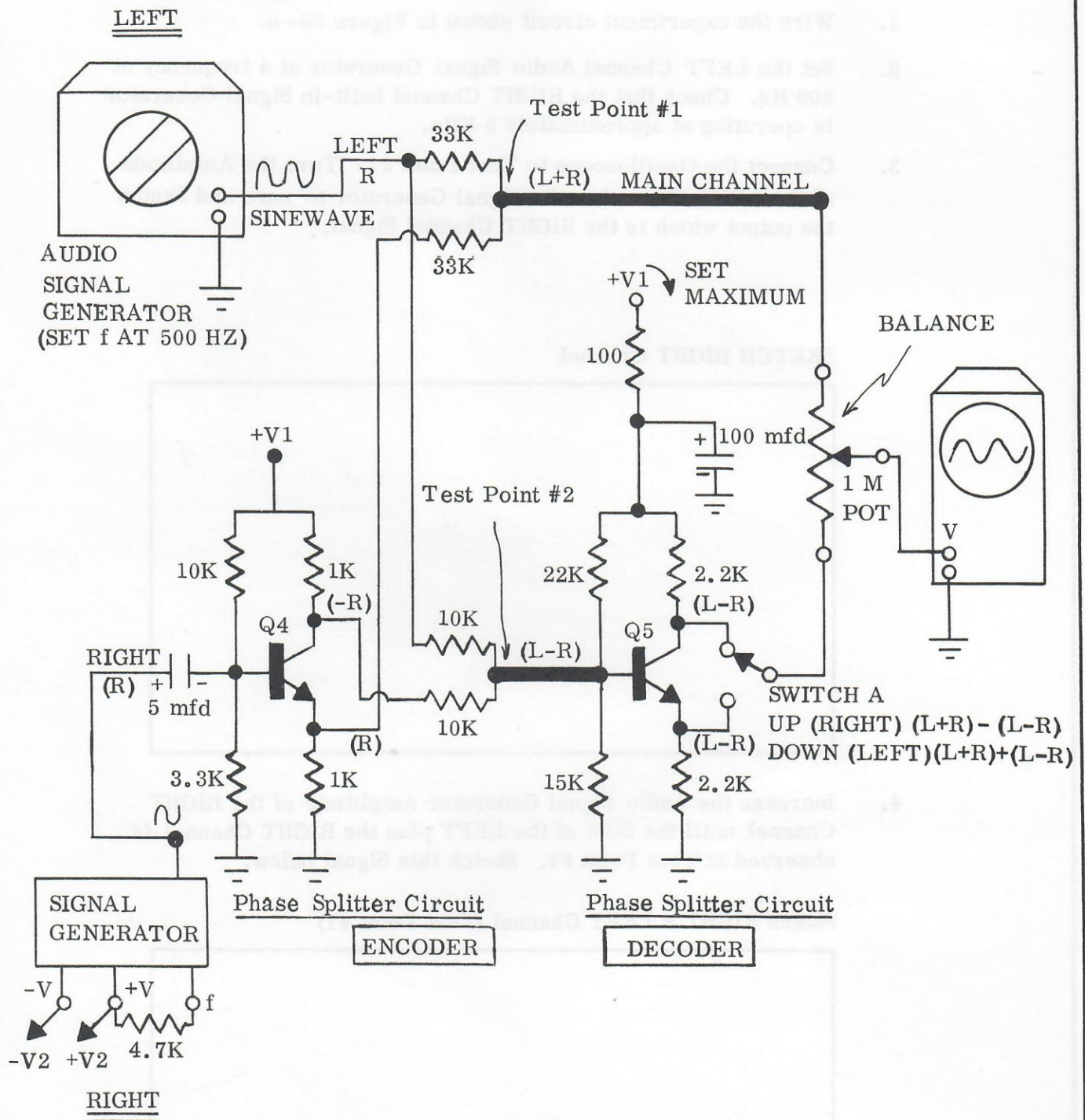
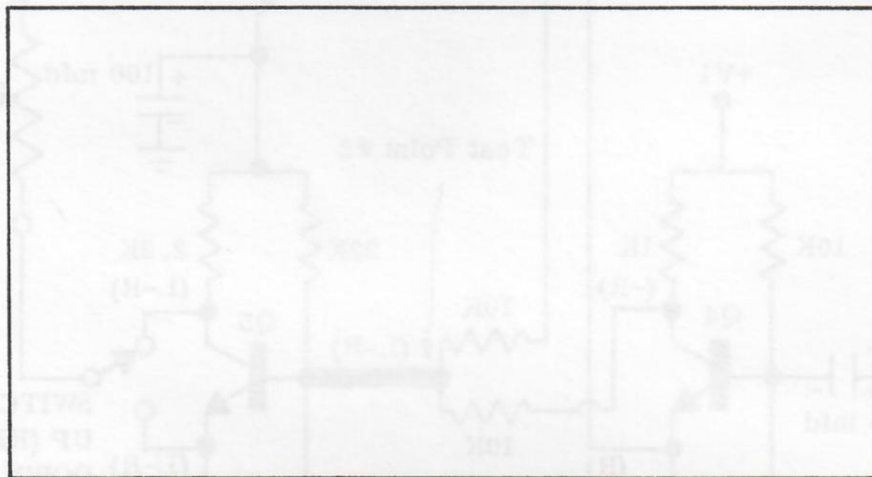


Figure 39-6 Stereo Multiplex - Encoder Decoder

Procedure:

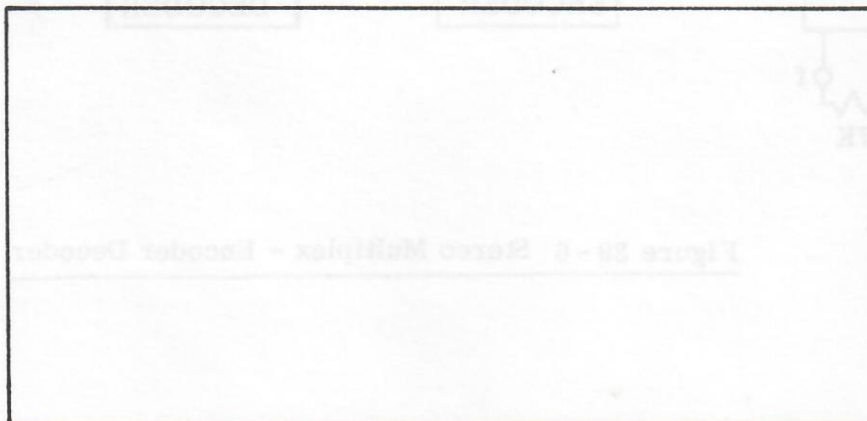
1. Wire the experiment circuit shown in Figure 39 - 6.
2. Set the LEFT Channel Audio Signal Generator at a frequency of 800 Hz. Check that the RIGHT Channel built-in Signal Generator is operating at approximately 3 KHz.
3. Connect the Oscilloscope to Test Point #1. Turn the Amplitude of the LEFT Channel Audio Signal Generator to zero and Sketch the output which is the RIGHT Channel Signal.

SKETCH RIGHT Channel



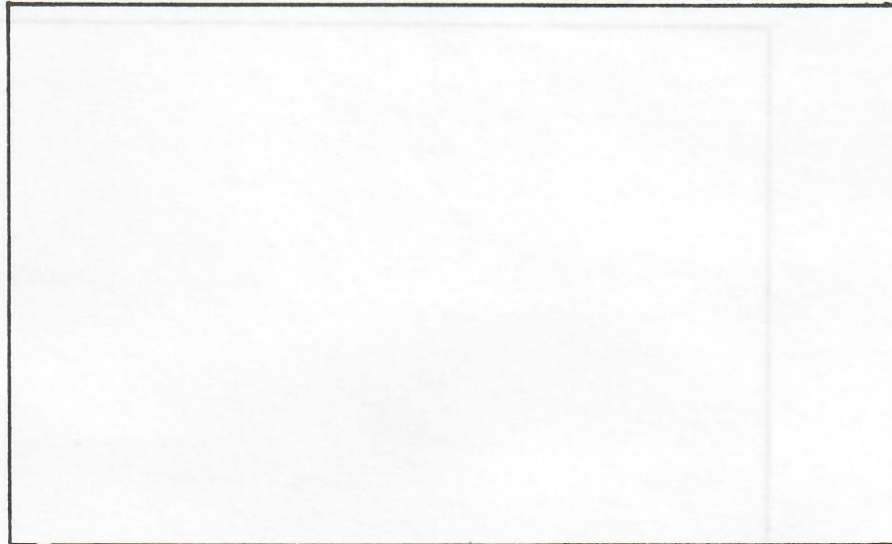
4. Increase the Audio Signal Generator Amplitude of the RIGHT Channel until the SUM of the LEFT plus the RIGHT Channel is observed at Test Point #1. Sketch this Signal below:

Sketch RIGHT + LEFT Channel (Test Point #1)



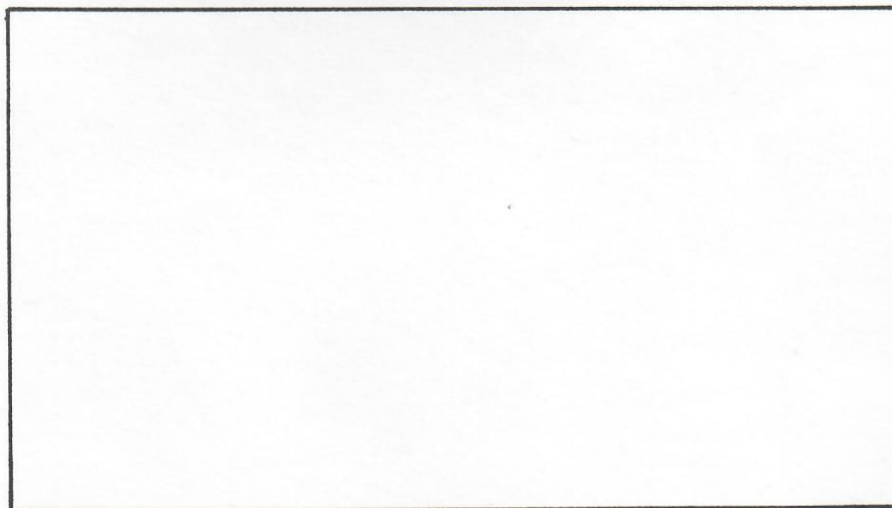
5. Connect the Oscilloscope to Test Point #2 (LEFT-RIGHT CHANNEL) and Sketch this waveform below:

Sketch LEFT - RIGHT (Test Point #2)



6. Monitor the OUTPUT obtained at the wiper of the 1 MEG POT. With Switch A UP, adjust the 1 MEG POT balance until only the RIGHT Channel Signal (Higher Frequency) is observed. Sketch the results below:

DECODED RIGHT Stereo Channel (Switch A UP).



7. With Switch A DOWN, adjust the 1 MEG POT balance until only the LEFT Channel Signal (Lower Frequency) is observed. Sketch the result below:

DECODED LEFT Stereo Channel (Switch A DOWN).



6. Monitor the OUTPUT indicated at the wiper of the 1 MEG POT. With Switch A UP, adjust the 1 MEG POT balance until only the RIGHT Channel signal (Higher Frequency) is observed. Sketch the results below:

DECODED RIGHT Stereo Channel (Switch A UP).



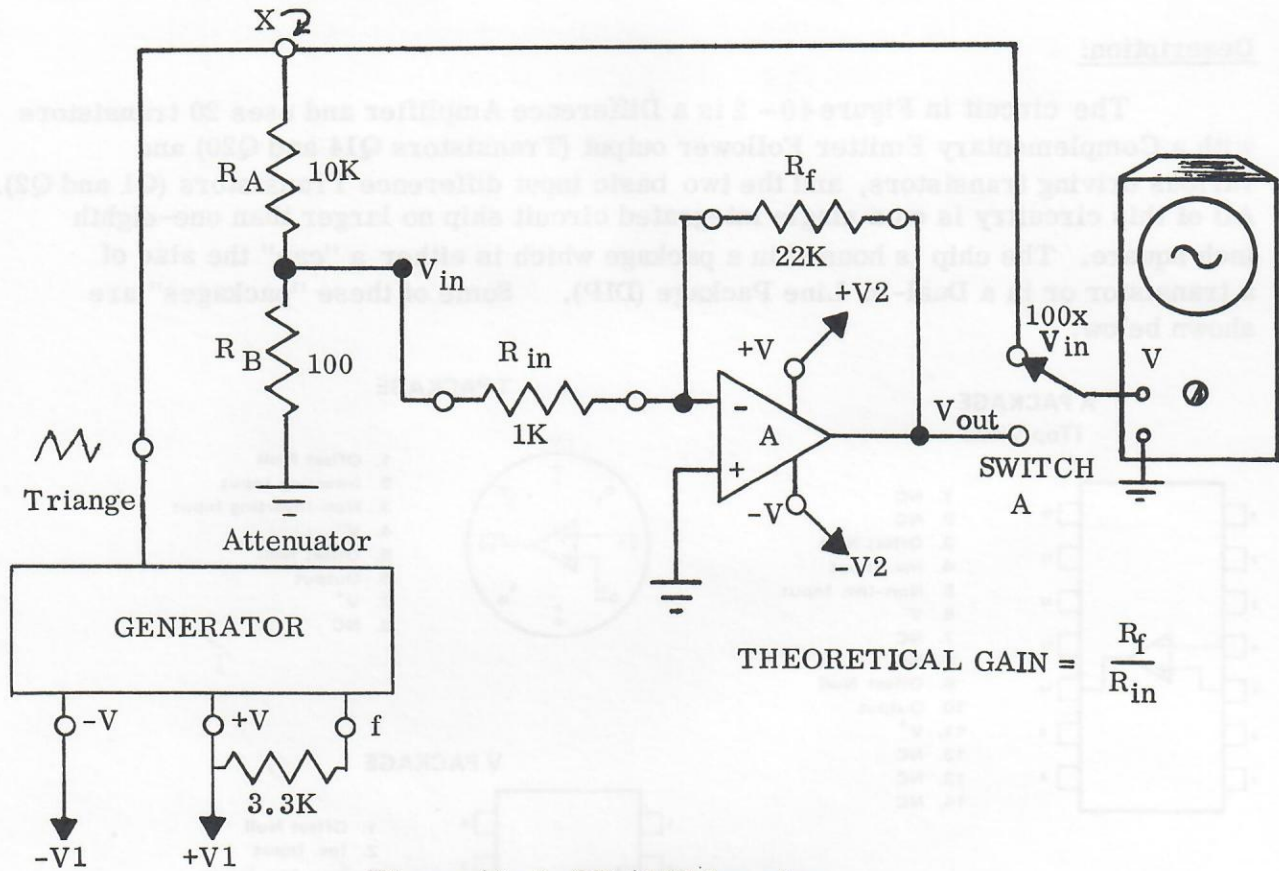


Figure 40 - 1 OP AMP Inverter

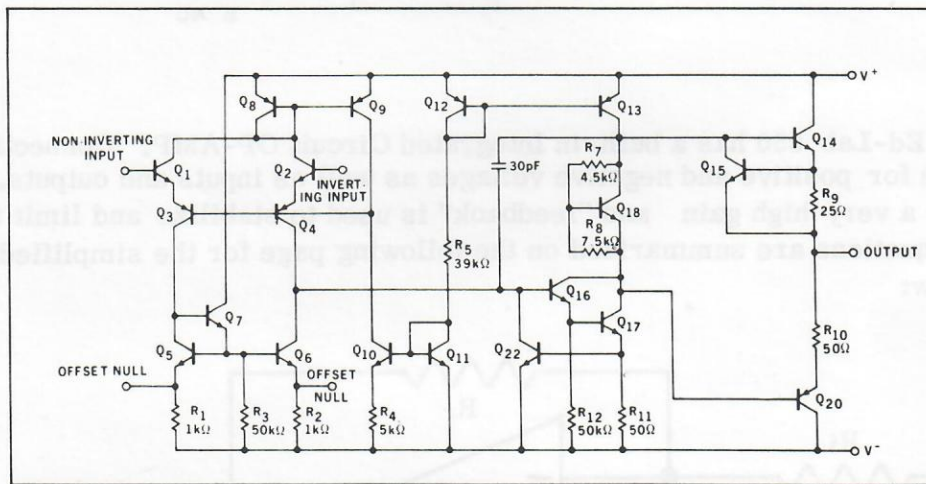


Figure 40 - 2 Equivalent Circuit OP-AMP

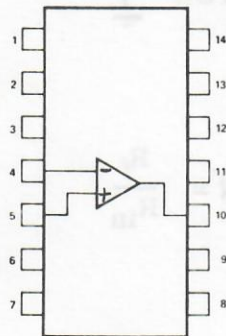
Objective:

You will use an Integrated Circuit Amplifier and observe the operation of the Integrated Circuit.

Description:

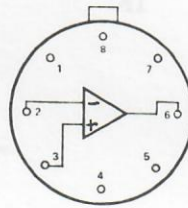
The circuit in Figure 40 - 2 is a Difference Amplifier and uses 20 transistors with a Complementary Emitter Follower output (Transistors Q14 and Q20) and various driving transistors, and the two basic input difference Transistors (Q1 and Q2). All of this circuitry is on a single integrated circuit ship no larger than one-eighth inch square. The chip is housed in a package which is either a "can" the size of a transistor or in a Dual-In Line Package (DIP). Some of these "packages" are shown below:

A PACKAGE
(Top View)



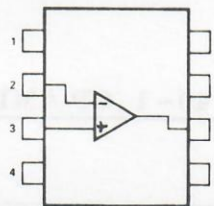
1. NC
2. NC
3. Offset Null
4. Inv. Input
5. Non-Inv. Input
6. V^-
7. NC
8. NC
9. Offset Null
10. Output
11. V^+
12. NC
13. NC
14. NC

T PACKAGE



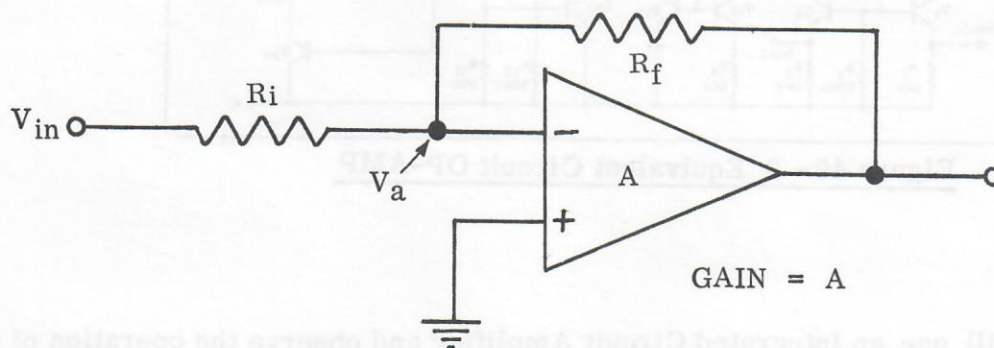
1. Offset Null
2. Inverting Input
3. Non-Inverting Input
4. V^-
5. Offset Null
6. Output
7. V^+
8. NC

V PACKAGE



1. Offset Null
2. Inv. Input
3. Non-Inv. Input
4. V^-
5. Offset Null
6. Output
7. V^+
8. NC

The Ed-Lab 650 has a built-in Integrated Circuit OP-AMP. Connections must be made for positive and negative voltages as well as inputs and outputs. The amplifier has a very high gain and "feedback" is used to stabilize and limit the gain. The equations are summarized on the following page for the simplified circuit diagram below:



$$(1) \quad V_{out} = A V_a$$

$$(2) \quad V_a = V_{in} \frac{R_f}{(R_i + R_f)} + V_{out} \frac{R_i}{(R_i + R_f)}$$

$$\text{substitute } V_{out} = A \frac{V_{in} R_f}{(R_i + R_f)} + A V_{out} \frac{R_i}{(R_i + R_f)}$$

$$V_{out} \left(\frac{1 - A R_i}{R_i + R_f} \right) = A V_{in} \frac{R_f}{(R_i + R_f)}$$

$$V_{out} (R_i + R_f - A R_i) = A V_{in} R_f$$

$$\frac{V_{out}}{V_{in}} = \frac{A R_f}{R_i + R_f - A R_i}$$

$$\frac{V_{out}}{V_{in}} = \frac{R_f}{\frac{R_i + R_f}{A} - R_i}$$

for large A:

$$\frac{V_{out}}{V_{in}} = - \frac{R_f}{R_i}$$

The overall system gain is negative and is the ratio of the two resistors.

Procedure:

1. Wire the circuit in Figure 40 - 1.

Be sure to connect the +V2 and -V2 Power to the OP-AMP.

2. The Voltage Divider R_A and R_B is used to provide a small input voltage given by the ratio:

$$\frac{10K}{100} = \frac{10,000}{100} = 100$$

3. Observe the input and output voltages with Switch A UP and DOWN. Enter the data below:

SWITCH A UP	V_x	=	peak to peak
SWITCH A DOWN	V_{out}	=	peak to peak

4. Calculate the Gain:

$$G = \frac{100 V_{out}}{V_x} = \underline{\hspace{2cm}}$$

$G =$

5. How does the Gain compare with the Ratio? _____

$$\frac{R_f}{R_i} = \frac{22K}{1K} = 22$$

6. Substitute various values for R_f as given in the table below:
Measure the Voltages, Calculate the Measured Gain, and Compare the Measured and Calculated Gains. You may want to change resistor R_A for the input signal amplitude.

		MEASURE		CALC. GAIN	CHECK
		Switch A UP	Switch A DOWN		
R_f	THEOR GAIN	V_x	V_{out}	$100 \frac{V_{out}}{V_x}$	
22K	22				
1K	1				
100K	100				
15K	15				
* 1M	1000				
$R_f = 3.3K$ $R_{in} = 10K$	0.33				
$R_f = 1K$ $R_{in} = 3.3K$	0.33				

*The Amplifier will saturate and clip the output signal giving a false result.

- shown below:
-
- The diagram shows a 16-pin integrated circuit (IC) socket. The pins are numbered 1 through 16. The top row of pins is numbered 1 through 8, and the bottom row is numbered 9 through 16. The socket is labeled "IC SOCKET". The power supply connections are indicated by arrows: $+V$ is connected to pin 7, and $-V$ is connected to pin 4. The diagram also shows the internal wiring of the socket, with pins 1 and 2 connected to the $+V$ supply, and pins 3 and 4 connected to the $-V$ supply.

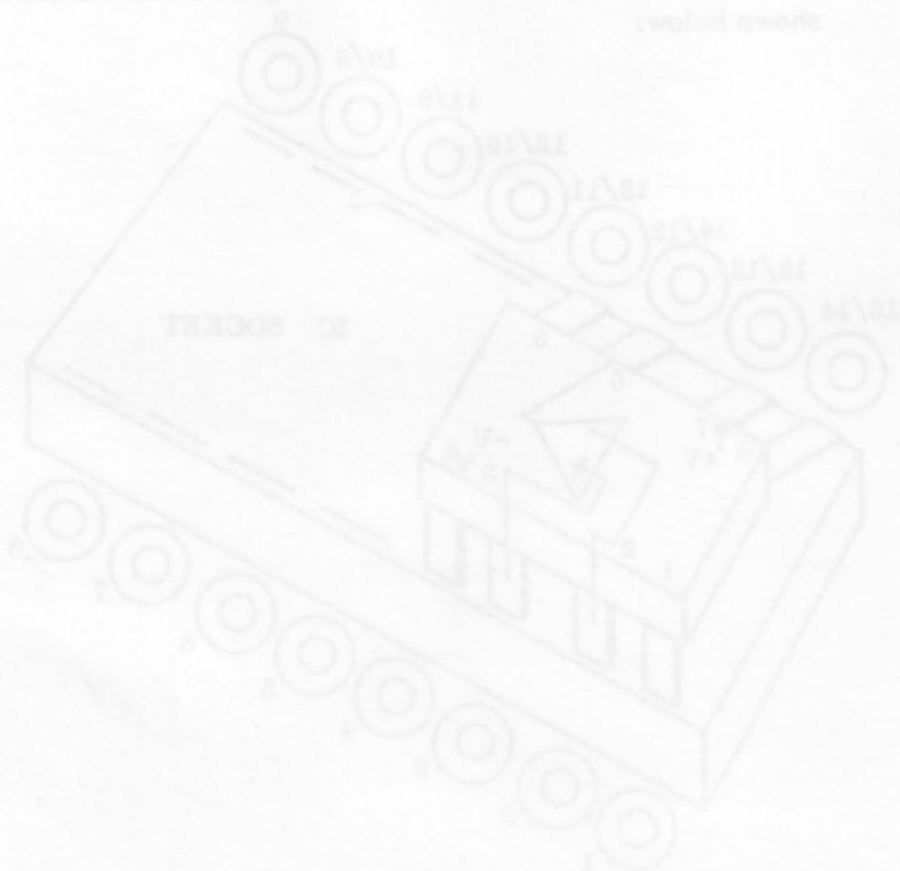
SWITCH A UP	$V_x =$
SWITCH A DOWN	$V_{out} =$

- $$G = \frac{100V_{out}}{V_x} = \underline{\hspace{2cm}}$$

G =

How does this gain compare with theoretical gain of 22? _____

7. The "V PACKAGE" Dual-In-Line Integrated Circuit has 8 pins as shown below:



If this Integrated Circuit is available, insert the IC in the Socket and repeat the test for the circuit in Figure 45-1 (using $R_1 = 52K$ and $R_2 = 1K$).

SWITCH A UP	$V_z =$
SWITCH A DOWN	$V_{out} =$

8. Calculate the Measured Gain as

$$\text{Gain} = \frac{V_{out}}{V_z} = \frac{100V}{V_z}$$

How does this gain compare with theoretical gain of 32?

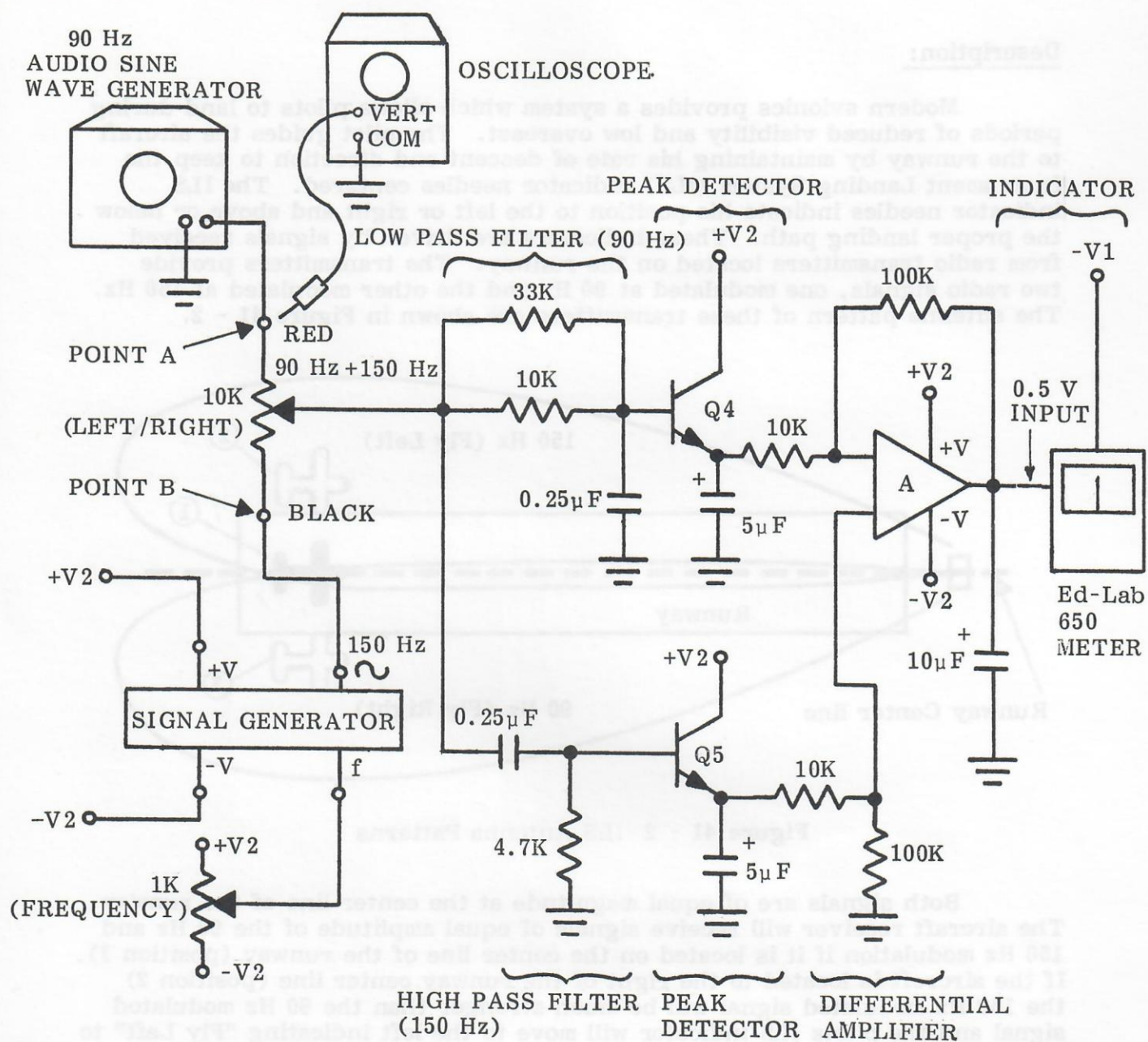


Figure 41 - 1 ILS Circuit Diagram

Objective:

To learn the principles of operation of aircraft Instrument Landing System (ILS) operation and to build and test the signal processing circuitry used to provide the pilot's ILS indicator signals.

Description:

Modern avionics provides a system which allows pilots to land during periods of reduced visibility and low overcast. The pilot guides the aircraft to the runway by maintaining his rate of descent and direction to keep the Instrument Landing System (ILS) indicator needles centered. The ILS indicator needles indicate his position to the left or right and above or below the proper landing path. These indicators are driven by signals received from radio transmitters located on the runway. The transmitters provide two radio signals, one modulated at 90 Hz and the other modulated at 150 Hz. The antenna pattern of these transmitters are shown in Figure 41 - 2.

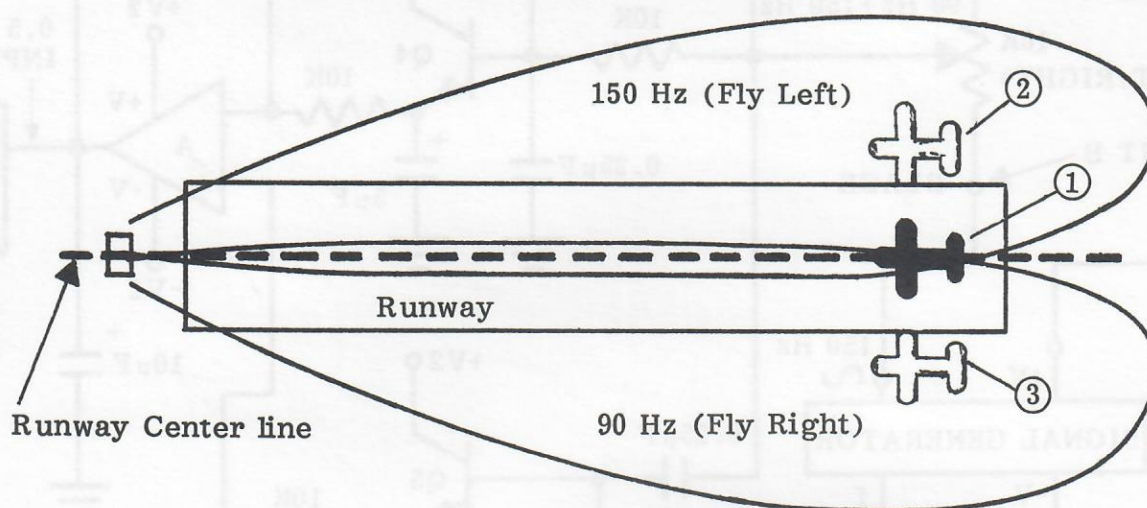


Figure 41 - 2 ILS Antenna Patterns

Both signals are of equal magnitude at the center line of the runway. The aircraft receiver will receive signals of equal amplitude of the 90 Hz and 150 Hz modulation if it is located on the center line of the runway (position 1). If the aircraft is located to the right of the runway center line (position 2) the 150 Hz modulated signal will be much stronger than the 90 Hz modulated signal and the pilots ILS indicator will move to the left indicating "Fly Left" to return the aircraft to the runway center line. The opposite situation will occur if the aircraft is to the left of the runway center line in the position indicated as (3) in Figure 41 - 2.

Both the 150 Hz modulated signal and the 90 Hz modulated signal are transmitted at the same carrier frequency, so a single receiver is used to receive the two signals and to demodulate the receiver output and to provide the 90 Hz and 150 Hz portions of the received radio signal. The circuit shown in Figure 41-1 uses the audio Sine Wave Generator to produce the 90 Hz signal and the Ed-Lab 650 Signal Generator to produce the 150 Hz signal. The 10K pot allows the proportion of each signal to the High Pass and Low Pass filters to be adjusted

to simulate a left and right of glide path situation. The combined 90 Hz and 150 Hz signals are applied to both filter inputs. The filter outputs are peak detected and connected to a differential amplifier to drive the indicator (Ed-Lab 650 Meter) left or right depending upon which frequency has the greater strength. A similar system of transmitters and antennas is used for Above and Below glide path indicators. This experiment only covers the left/right ILS indicator system.

Procedure:

1. Wire the circuit shown in Figure 41 - 1.
2. Connect the Oscilloscope to the Sine Wave Output of the Ed-Lab 650 Signal Generator (Point B).
3. Adjust the 1K Pot for an output frequency of 150 Hz or as close to this frequency as is possible. A 150 Hz signal has a Period (one cycle) of 6.6 milliseconds.

Record the Period of the signal you were able to obtain.

T = _____ milliseconds

Calculate the frequency:

$$F = \frac{1}{T} = \text{_____ Hz}$$

4. Record the Amplitude (peak to peak) of the Waveform from the Ed-Lab 650 Signal Generator.

AMPLITUDE (Peak to Peak) = _____ VOLTS

5. Adjust the frequency dial of the external Audio Sine Wave Generator to 90 Hz.

6. Connect the oscilloscope to the output of the Audio Sine Wave Generator (Point A) and adjust the amplitude of the 90 Hz signal to the same amplitude as measured in Step 4.

AMPLITUDE (Peak to Peak) 90 Hz = _____ VOLTS

7. Center the 10K Left/Right Potentiometer (Reference line straight up).
8. Adjust the - V1 power supply control knob to obtain a "CENTER" reading on the Ed-Lab 650 meter. The needle should point straight up.
9. The "ILS" system is now calibrated for center line glide path indication. The meter needle should indicate 5 on the 10 V scale.

(Note that the meter is actually used on the 0.5 V scale).

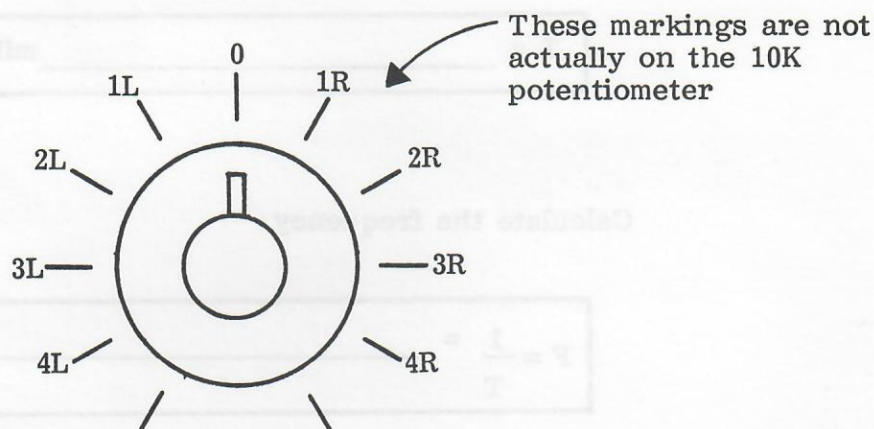


Figure 41 - 3 10K Pot (Left/Right) Knob

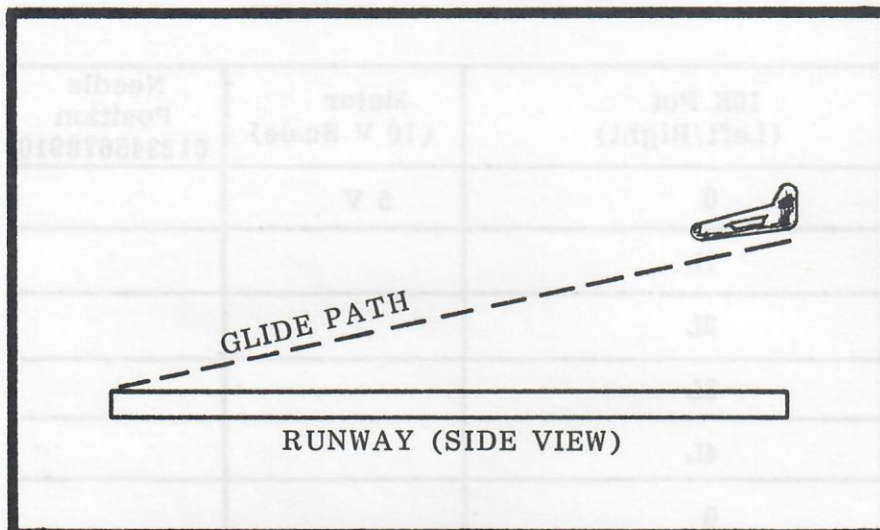
10. Set the 10K Pot (Left/Right) to the positions indicated in the Table. Record the Meter Reading of the Ed-Lab 650 meter (read the 10 V scale).

10K Pot (Left/Right)	Meter (10 V Scale)	Needle Position 012345678910
0	5 V	
1L		
2L		
3L		
4L		
0		
1R		
2R		
3R		
4R		

11. Does the meter needle respond to the change in Pot setting?

Questions:

- Does the meter needle indicate the correct direction to place the aircraft on the glide path? (i.e. when the Pot is moved to the left does the needle move to the right? _____)
- Draw a sketch (side view) of the antenna patterns required to provide the signals necessary to maintain the vertical position of the aircraft on the glide path.



3. What would be the effect on the position of landing aircraft if the amplitude of the 90 Hz and 150 Hz transmitters were different?

4. Landing is a very critical flight condition, especially in poor weather conditions. Do you think this is the only radio aid used by pilots to land in low visibility?

Answer: During poor visibility the pilot has several other systems which aid him in being absolutely sure that his instrument information is correct. As the pilot approaches the runway he passes over a system of three marker beacons. Each beacon is located a specific distance from the touchdown point. They are called Outer Marker, Middle Marker and Inner Marker. As the aircraft passes over each marker beacon, a light on the pilots instrument panel turns on, indicating the distance from the touchdown point. The pilot will check his altitude at each marker beacon and will judge his distance from the touchdown point as he passes each beacon. A precision radar approach is also available at most large airports. The radar operator

can communicate directly with the pilot in this situation and verbally tell him how to correct his position for a safe landing. The Left/Right information, however, is largely dependent upon the ILS instrumentation. A failure in the ILS system is a serious situation. Special and emergency procedures would be immediately employed if a failure in the ILS system was discovered.

can communicate directly with the pilot in this situation and verbally tell him how to correct his position for a safe landing. The left/right information, however, is largely dependent upon the ILS instrumentation. A failure in the ILS system is a serious situation. Special and emergency procedures would be immediately employed if a failure in the ILS system was discovered.

Objectives:

1. To study the various blocks that form a phase locked loop (PLL).
2. To build a functioning phase locked loop.
3. To build a PLL based Frequency Multiplier.

Equipment Needed:

1. Ed-Lab 651 Trainer.
2. CD 4046 CMOS Phase Locked Loop IC.
3. Dual Trace Oscilloscope (CES 4708 or equal).
4. Digital Frequency Counter (CES 4185 or equal or use oscilloscope).

Description:

Phase locked loop circuitry is very popular because of its extensive use in FM tuners, frequency multipliers and FSK detectors. The PLL is basically a servo system which finds and locks on to signals even under extremely noisy conditions. It consists of the following building blocks.

1. A phase detector or comparator
2. A low pass filter
3. A voltage controlled oscillator (or VCO)

The phase detector as the name suggests detects the phase relationship between two signals and produces an output which is an average, or DC Voltage that is related to the phase difference between the two signals.

The low pass filter allows DC and low frequency signals to pass through and attenuates or cuts the high frequency signals. The output of this filter is an average or DC Voltage.

The Voltage Controlled Oscillator produces an output frequency signal whose frequency varies with the DC Voltage applied to the VCO.

The phase locked loop is formed by interconnecting the components as shown in Figure 1.

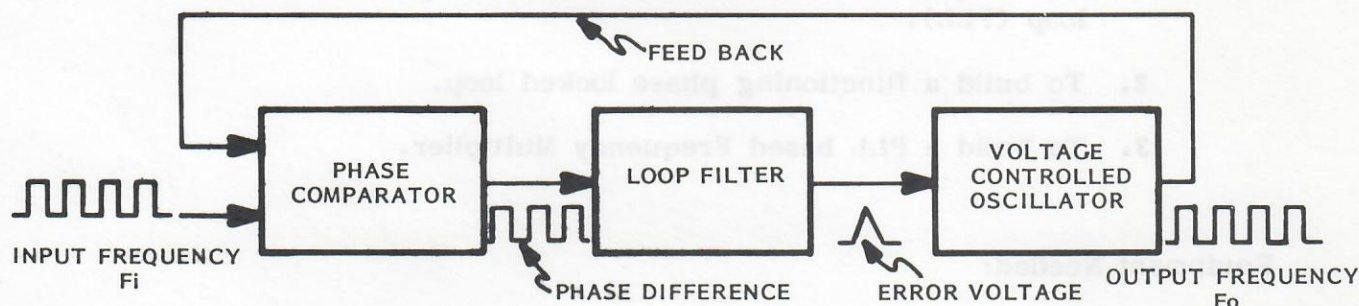


FIGURE 1 - BASIC PHASE LOCKED LOOP.

When no DC Voltage is present at the input of the VCO the VCO oscillates at a frequency determined by the external resistor and capacitor connected to it. This frequency is compared to the incoming signal by the phase comparator. This VCO output frequency is called the free running frequency.

When the VCO output is connected to the phase comparator (Figure 1) it is compared to the incoming signal. The phase comparator output is now a voltage whose magnitude is a function of the phase and frequency difference of the two signals. This voltage after filtering is applied to the VCO. The VCO frequency F_o now shifts in a direction which tends to approach more closely the input frequency F_i . Since this is being fed back to the phase comparator input, the loop will try to lock on to the input frequency.

Once the VCO starts to change frequency it is said to be in the "capture" state and its frequency continues to change until the output frequency F_o , is the same as the input frequency F_i . When this occurs the PLL is said to be in the "locked" state, where the loop frequency varies exactly with the input frequency.

If a frequency divider is inserted in the feedback path from the VCO to the phase comparator, the VCO, to balance the loop will increase frequency N times, where N is the frequency division inserted in the feedback path.

Frequency output F_o is now

$$F_o = NF_i$$

Thus the loop has three states:

1. Free running
2. Capture
3. Lock

The capture range of frequency is not as wide as the locking range. The low pass filter is a critical element in the loop, it restricts the capture band and reduces tracking speed because of the "integrating" action of the circuit, it also supplies the PLL with a short duration "memory" even if the signal should drop into a "noise" level for several cycles, the filter will continue to vary the VCO at the same rate till it picks up the signal again. Since these two aspects work in opposite ways the filter design is a "trade-off" or compromise of the two factors.

Figure 2 shown the block diagram and pin outs for the CD 4046 CMOS micropowered phase locked loop used in this experiment.

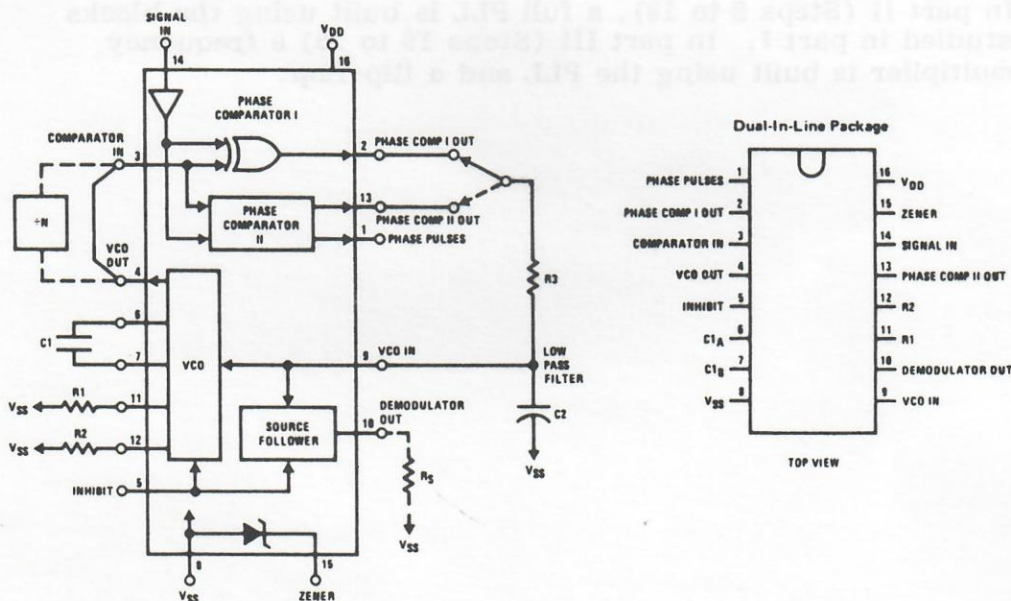


FIGURE 2 - BLOCK DIAGRAM AND PIN OUTS FOR THE CD4046 PHASE LOCKED LOOP.

The 4046 has two phase comparators PC1 and PC2. PC1 is an exclusive OR gate which provides good noise immunity, but it has a tendency to lock on to harmonics of the VCO and it needs a 50% duty cycle. PC2 is a complex network built around edge triggered Flip-Flops and gates and has a higher immunity to harmonics. The outputs of PC1 and PC2 are on pins 2 and 13. The input signal on pin 16 is amplified by an input amplifier.

The VCO center frequency is set by Capacitor C1 and by one or two resistors, R1 or R1 and R2. When only R1 is used the VCO frequency may be varied from 0Hz when control voltage at pin 9 is at GND (V_{DD}) to $F_{max} = 1/R1 (C1+32PF)$ when pin 9 is at Supply Voltage. Resistor R2 provides a "offset" of VCO minimum frequency from 0Hz to $F_{min} = 1/R2 (C1+32PF)$. A Buffered Version of the VCO input voltage is available on pin 10 and is usefull in demodulation applications. Pin 5 is an enable or inhibit input which permits the VCO to be shut off to conserve power during standby mode.

A Zener diode has been internally provided for voltage regulation. The experiment which follows is in three parts, in part I (Steps 1 to 8) the PLL building blocks are studied. In part II (Steps 9 to 18), a full PLL is built using the blocks studied in part I. In part III (Steps 19 to 25) a frequency multiplier is built using the PLL and a flip-flop.

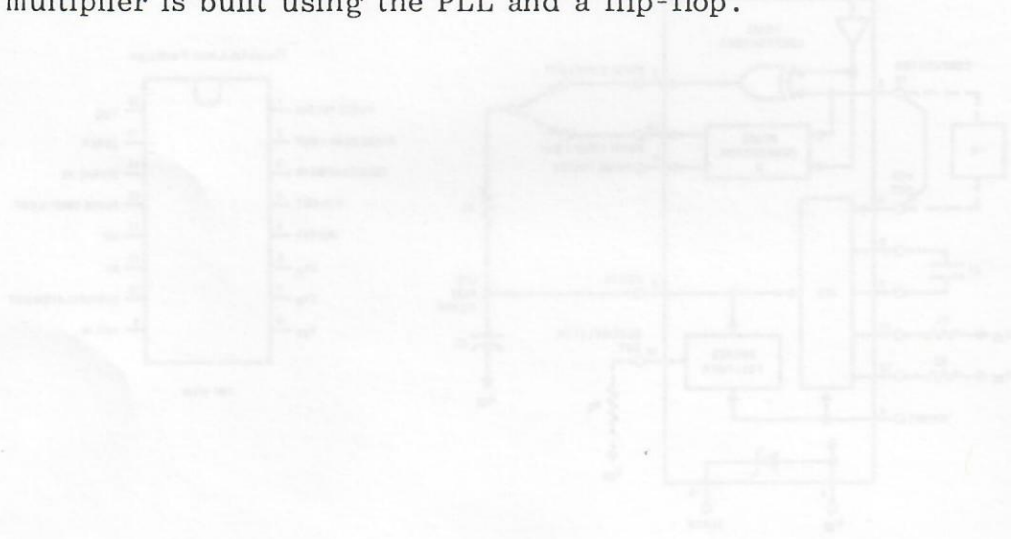


FIGURE 2 - BLOCK DIAGRAM AND PIN OUTS FOR THE CD4046 PHASE LOCKED LOOP.

I PHASE DETECTOR OR COMPARATOR.



1. Wire the circuit of Figure 3. Set clock 5KHz.
2. Set the scope controls as follows.
Vertical: 2V/DIV, Horizontal: 50mS/DIV, Trigger: CH1
3. Keep Switch A down. The Exclusive OR gate has a '0' on one of its inputs. The waveforms on CH1 and CH2 will be in phase.
Are the waveforms in phase? _____
4. Keep Switch A up and the gate now acts like an inverter.
Are the waveforms out of phase? _____
5. You will now build a RC phase shifting network and observe the change in the DC or average voltage at the output of the exclusive OR gate. Wire the circuit of Figure 4.

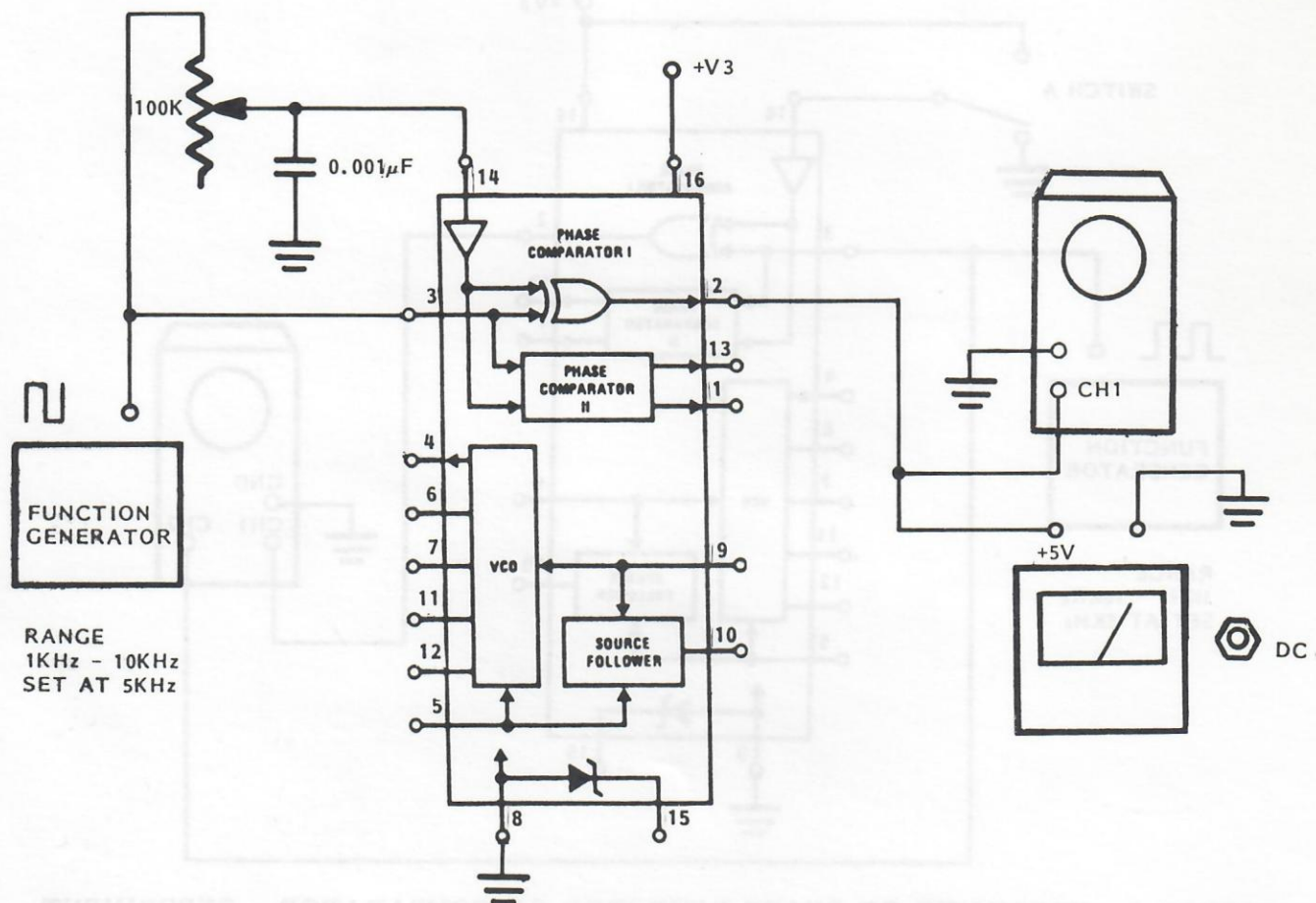
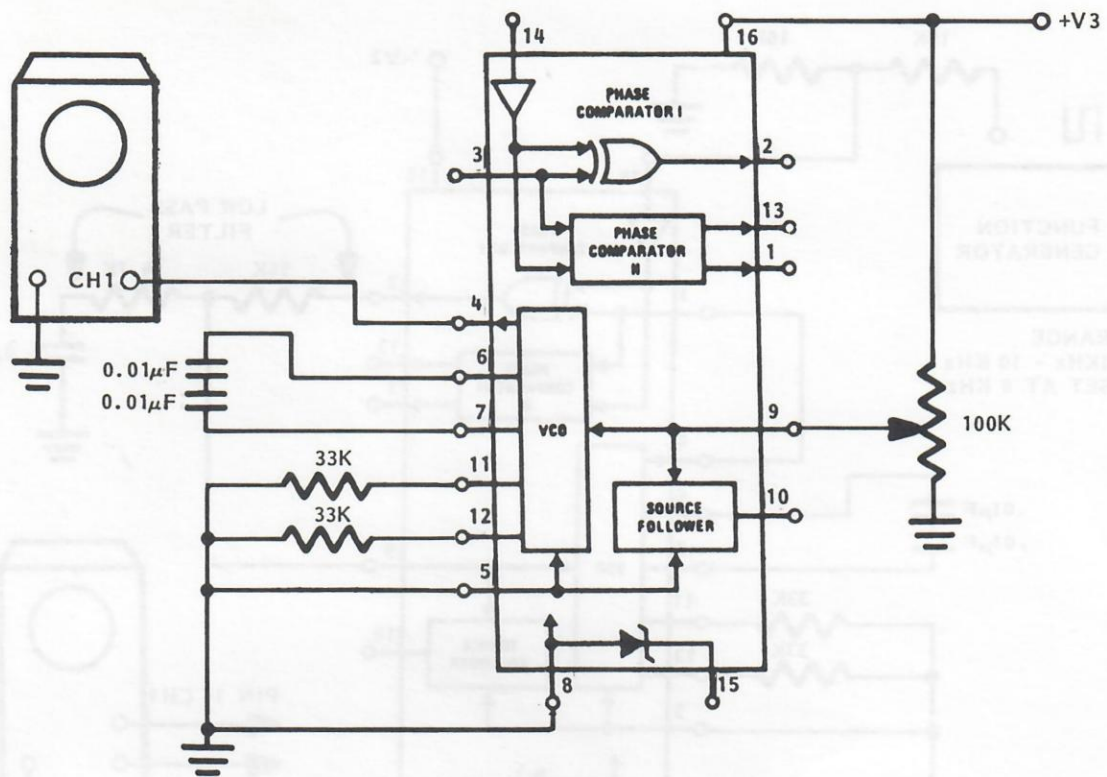


FIGURE 4 - PHASE COMPARATOR WITH A RC PHASE SHIFTING NETWORK.

6. Set scope controls as in step 2. Vary the 100K potentiometer and observe the waveform and meter reading.

Does the meter reading vary with phase? _____

7. Remove all prior wiring and wire the circuit shown in figure 5.



8. Keep the 100K potentiometer turned completely counter clockwise. Observe the waveform, increase the voltage input to the VCO by rotating the 100K potentiometer.

Does the VCO frequency vary with voltage?_____

PHASE LOCKED LOOP.

9. Various blocks of the PLL studied earlier will now be interconnected to result in a full working phase locked loop. Remove all previous wiring and wire the circuit of Figure 6.

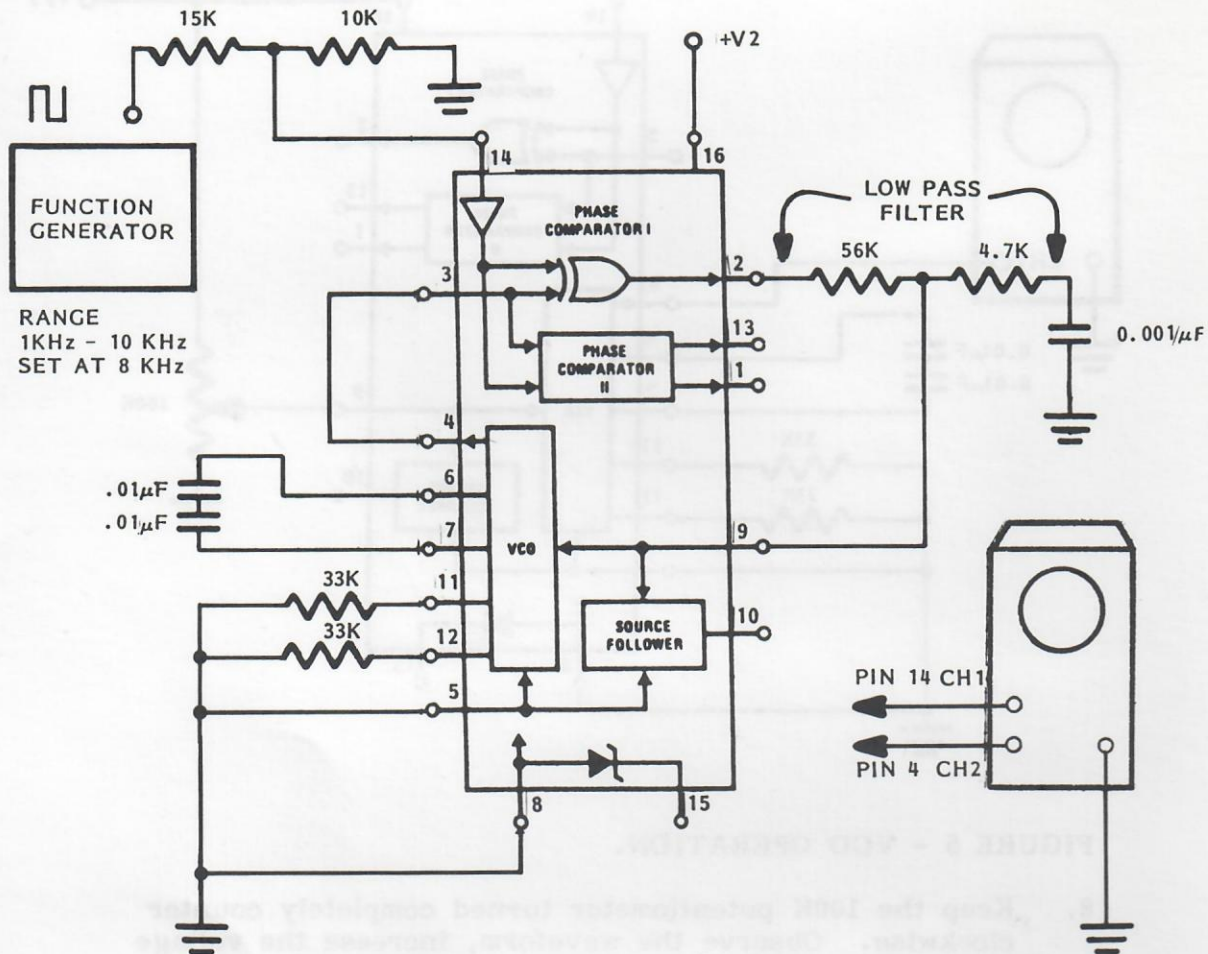


FIGURE 6 - COMPLETE PHASE LOCKED LOOP.

10. Set your scope controls as follows

Vertical: 2V/DIV

Horizontal: 50ms/DIV

Triggering: Vertical mode or CH1

Set the clock range switch to 1K-10K and frequency to 8K.

11. The output frequency should now be exactly the same as the input. With a digital frequency counter measure the input and output frequencies.

Input Frequency = _____

Output Frequency = _____

Are the frequencies exactly the same? _____

12. With a lead temporarily connect pin 9 VCO input to GND (VSS, pin 8) and record the VCO output frequency.

F min = _____

13. Temporarily connect pin 9 VCO input to the Supply Voltage (VDD pin 16) and record the VCO output frequency.

F max = _____

14. Observing the input and output waveforms on the Scope, gradually vary the input frequency from 7.5 KHz to 8.5 KHz. You will observe that the output frequency follows the input. The loop is in the "locked" state.

15. Gradually reduce the input frequency and note down the frequency at which the VCO output stops following the input. Measure this frequency.

FL min = _____

16. Gradually increase the input frequency and get the loop into the locked state as before. Keep increasing the frequency till the point where the output frequency stops following the input. Measure this frequency.

FL max = _____

17. Compare the frequencies FL min and FL max to F min and F max they should be nearly equal. This range of frequencies over which the PLL follows the input frequencies is called the lock range.

Calculate the lock range FL max - FL min.

Lock Range = _____ Hz

18. DO NOT disconnect this circuit proceed to step 19.

FREQUENCY MULTIPLIER.

19. Figure 7 indicates the basic PLL scheme used to multiply an input frequency. Figure 8 indicates a basic Flip-Flop which divides frequency by 2 and will be inserted into the feedback path of the PLL to achieve a frequency multiplication by 2.

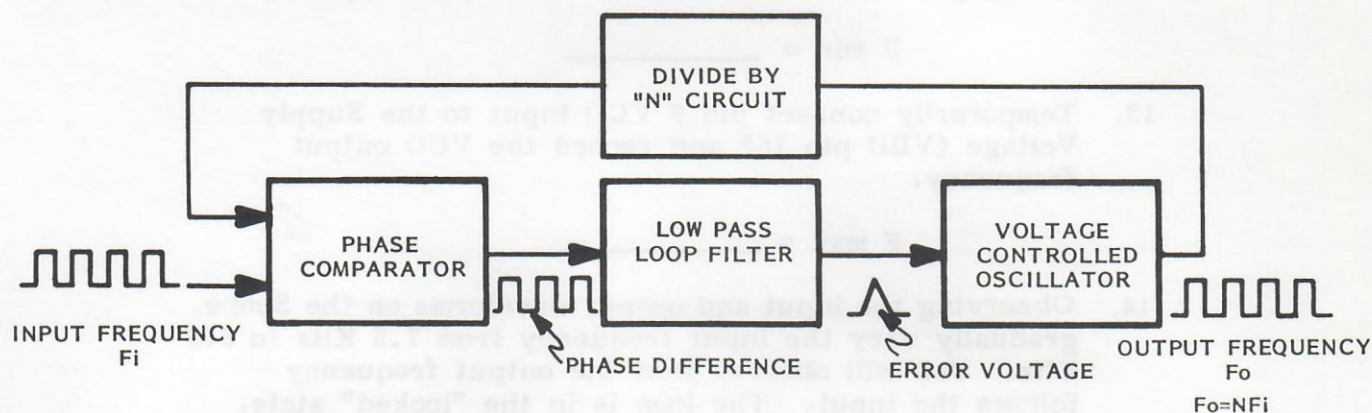


FIGURE 7 - BASIC PHASE LOCKED LOOP FREQUENCY MULTIPLIER.

20. Wire the Flip-Flop of Figure 8. This divide by two circuit will be later placed in the feedback path of the PLL.

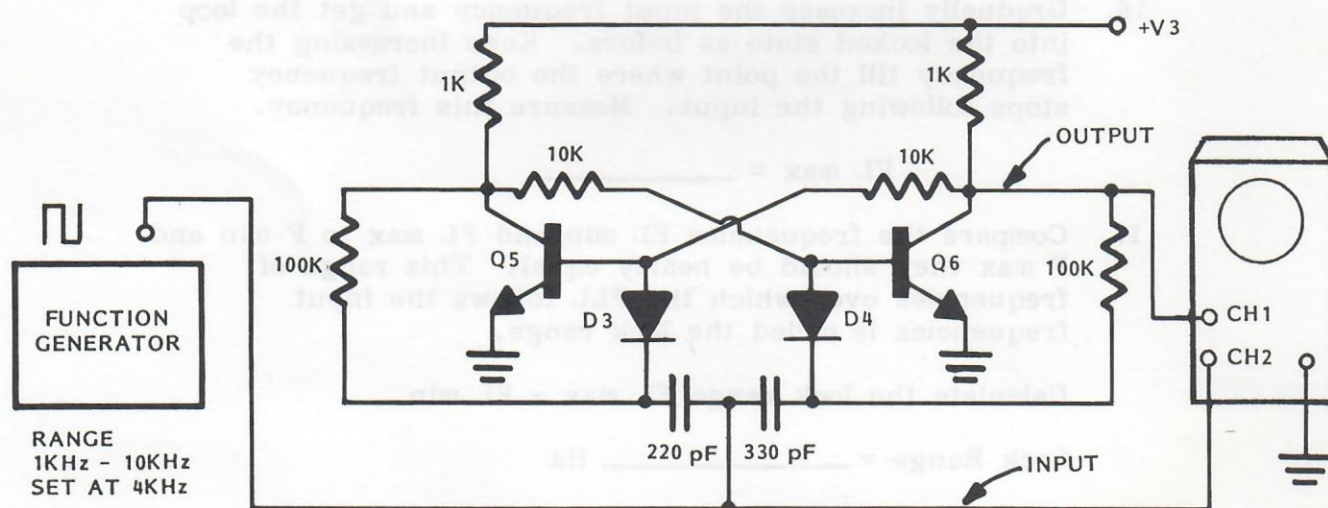


FIGURE 8 - FLIP-FLOP

21. Set the scope as follows:

Vertical = 2V/DIV

Horizontal = 50 msec/DIV

Trigger = Vertical mode or CH1.

Observe the input and output frequencies.

Is the Flip-Flop dividing the input frequency by two? _____

22. Insert the Flip-Flop into the feedback path of the PLL as shown in Figure 9.

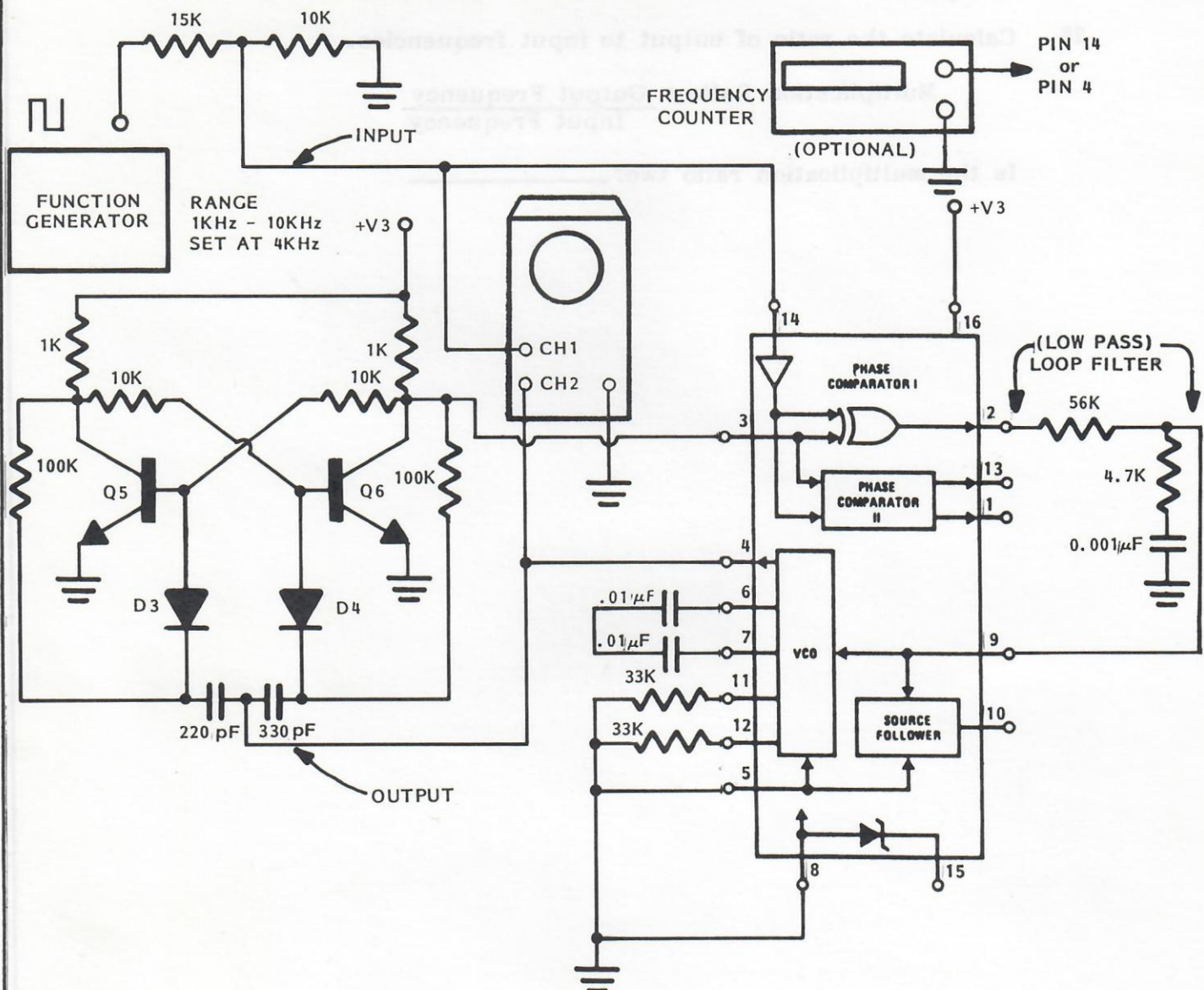


FIGURE 9 - A PLL BASED FREQUENCY DOUBLER.

23. Vary the input frequency and measure the minimum and maximum frequencies within which the PLL is in "lock".

F min = _____ F max = _____

24. With the frequency counter measure the input and output frequencies with the PLL in "lock" state.

Input Freq = _____

Output Freq = _____

25. Calculate the ratio of output to input frequencies.

$$\text{Multiplication Ratio} = \frac{\text{Output Frequency}}{\text{Input Frequency}}$$

Is the multiplication ratio two? _____



FIGURE 9 - A PLL BASED FREQUENCY DOUBLER

ASSIGNMENT:

1. What are the building blocks of the PLL?
2. What are the three states of the PLL?
3. What is the function of the low pass filter?
4. What is the difference between the "capture" and "lock" states of the PLL?
5. List three applications for the phase locked loop.

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